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GEOPHYSICAL RESEARCHES IN MARINE GEOLOGY[1,2]

by

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The study by geophysical methods of the structure and development of the earth's crust in the ocean areas is one of the most important tasks of marine geology. In addition to the general investigation of the structure of the earth's crust by geophysical methods in remote parts of the ocean, in the areas of the continental shelf more detailed geophysical work is being done in searching and prospecting for oil deposits, sometimes in connection with the solution of problems in engineering geology.

This article describes the status and the prospects of magnetic, gravitational, electrical and seismic prospecting in the sea and cites examples of such work being done in the U.S.S.R.

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1. Geophysical methods of studying the earth's crust are of particular importance in maring geology. Only through the application of these methods in recent years has it become possible to provide well-founded solutions to problems of the structure and development of the earth's crust in the ocean region.

Complex geophysical work on ships, using gravimetric, seismic and magnetic methods, has enabled us to study the structure of the earth's crust in the area of the ocean, to distinguish the different types of crust and to trace deep faults. More detailed geophysical operations, using all the known methods, have been widely applied to the study of the continental shelf, within which in recent years there has been a great expansion of exploration and prospecting for oil and gas deposits.

Seismic prospecting in combination with electrical prospecting are effectively solving the problems of marine engineering geology that arise in connection with the construction of harbors, of drilling platforms for wells in the sea, of breakwaters, etc.

Of extreme interest for explaining the structure of present-day geosynclines is the zone of transition between the continental and oceanic types of crust: an example is the Pacific Ocean coast of the Soviet Union. The Kurile and Aleutian island arcs are bordered by very deep trenches in the Pacific Ocean. The transitional zone is also characterized by earthquake foci located tens and hundreds of kilometers deep. Here, too, originate the ocean tidal waves, or "tsunamis", which cause such great damage to the economy of the littoral zone.

The earth's crust beneath the waters of the seas and oceans far from shore is also a very important object of geophysical research. The crust here is not uniform; in the Atlantic Ocean, for instance, lies the submarine Atlantic Ridge, beneath which the crust is thicker, so that this zone approaches the continental crust in type.

Study of the structure of the earth's crust in the region of the shallow-water continental shelf is of great practical importance in connection with the search for oil and gas. The total area of the continental shelves throughout the world is more then 25 million square kilometers, and the volume of possible oil-bearing sediments on the shelf, down to the 100 meter isobath level, is greater than the volume of such sediments on dry land. At the present time many countries, including the U.S.S.R., the U.S.A., West Germany, England, Italy and others, are carrying on extensive geophysical prospecting operations in the areas of the continental shelf. Geophysical investigations here are directed

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toward detailed study of the general geologic structure in the littoral zones of oil-bearing regions, prospecting and the preparation for deep exploratory drilling of structures likely to contain oil and gas.

The first geophysical investigations in the sea were carried out in the twenties of this century, when Vening-Meinesz (of Holland) developed a method of making gravimetric determinations at sea. In the U.S.S.R. marine geophysical investigations began in the 1930's. They are now being used to study the general geologic structure of the seas and oceans and also in connection with exploration and prospecting for oil deposits [25]. In recent years this work has been done much more intensively than earlier, and has encompassed not only the coastal waters of the U.S.S.R. but also the remote areas of the ocean. Large-scale marine geophysical investigations were undertaken by the Soviet Union in 1957-1958, as part of the program of the International Geophysical Year, in the Pacific Ocean, the Sea of Okhotsk, the Japan and the Bering Seas, and in other parts of the world ocean.

Instruments and methods developed for use on dry land were at first adapted to geophysical work in the sea. Later on, special procedures and equipment were elaborated for marine geophysical prospecting.

The status and the future prospects of marine geophysical exploration will be briefly described below, drawing for examples on the work done by the Soviet Union in recent years.

2. Aerial magnetic surveys in the U.S.S.R. have been made over the Caspian Sea, the Sea of Okhotsk and the Sea of Azov, as well as over the Pacific Ocean. Continuous-record towed aerial megnetometers were used for this work.

The towed aerial magnetometers (AEM-49, ASGM-25) with ferromagnetic elements were installed in a bimotor airplane with a towed gondola. The change in the modulus of the total vector of geomagnetic field intensity, ΔT_a, was measured with an error of ± 5 to 10 gammas. Observations were made in the air at altitudes of 500 to 3000 meters, along parallel traverses some 20 to 28 kilometers distant from each other. The determination of the coordinates was tied into coastal orienting points. The total error of the survey where the contours failed to close was estimated at ± 30 gammas. This survey has made it possible to construct small-scale maps of magnetic anomalies; an example of such is the aeromagnetic survey of the Caspian Sea.

The curves of the anomalies ΔT_a and the overall magnetic map of the Caspian Sea clearly reveal two regional zones of magnetic maxima. The northern zone extends from the eastern end of the Donets basin through the Volga River delta and the northern part of the Caspian Sea, branching out in one direction toward Mugodzhar and the Southern Urals, and in another toward Mangyshlak. It indicates the presence of an enormous deep fault at the boundary between the Precambrian platform of the Russian plain and the Paleozoic platform of the Northern Caucasus, the Ust'-Urt and the Kara-Kum regions. The magnetic anomalies here are apparently caused by the residual magnetization of the basic magma, which rose up from the depths along the deep fault zone. The southern zone of magnetic maxima has the same origin. This has been encountered in the northern part of the Sea of Azov, stretching out along the northern foothills of the Greater Caucasus and intersecting the Caspian Sea in the direction of Makhach-Kal-Krasnovodsk. This separates the Paleozoic platform of the Northern Caucasus, Ust'-Urt and Kara-Kum from the Tertiary geosynclinal zone of the Caucasus. Within these vast belts of magnetic anomalies, the individual local maxima of 400 to 800 gammas are disposed en échelon (Fig. 1). This means that the deep faults actually consist of whole systems of faults, each of which has served as a channel for the rise of basic magma.

Detailed aeromagnetic surveying in the area of the Apsheron Peninsula has shown the existence of a system of weak magnetic anomalies, of the order of 20 to 40 gammas, trending northwest-southeast, which are clearly associated with the Tertiary folding in this region. In the opinion of some investigators, the presence of magnetite in the sands of the Produktivnaya series perhaps has some effect here. It is more appropriate to assume, however, that the weak magnetic anomalies at the southeastern end of the Caucasus are connected with the deep structure of the granitic-basaltic crust in this region.

The experience of aeromagnetic operations over the seas indicates the close connection between magnetic anomalies and the main tectonic features of the earth's crust, both on a regional and on a local scale.

Magnetic surveys over the sea have also been made by means of magnetometers installed on ships. In this manner, measurements of the elements of the geomagnetic field have been made on board the non-magnetic vessel "Carnegie" (U.S.A.). More refined magnetic instruments with magnetosaturated receivers have been installed aboard the Soviet non-magnetic ship "Zarya" ("Dawn"), which has carried out worldwide magnetic surveys under the program of the International Geophysical Year [9]. For prospecting

FIGURE 1. Magnetic anomalies in the Caspian Sea region (after O.N. Solov'yev):

1 -- Zones of increased magnetic anomalies; 2-4 -- zones of reduced magnetic anomalies; 5 -- axes of magnetic anomalies.

urposes, as early as 1948 in the U.S.A. ıere was an attempt to make magnetic meas-rements with a small non-magnetic barge owed several tens of meters behind a self-ropelled ship [10]. At that time, however, ıe small number and low accuracy of such ıeasurements did not permit any large opera-ions of this type. Now, with the appearance f nuclear-resonance magnetometers, which o not require orientation in space, magnetic bservations on board ship for detailed sur-eys have been renewed, although still on an xperimental basis.

3. Gravimetric operations at sea are being arried with pendulums and gravimeters on hips, and also with bottom gravimeters [10]. arge seagoing vessels or submarines permit ıeasurements of the force of gravity at any epth, with the small error of ± 3 to 15 milli-als. Such measurements were first made in 1923, when Vening-Meinesz suggested a method of eliminating the ship's acceleration by means of two pendulums oscillating on the same support. The first observations with pendulums in the U.S.S.R., using Vening-Meinesz's method, were made in the Black Sea in 1930 by L.V. Sorokin [22]. Since then, observations with pendulums have also been made in the Arctic basin, the Caspian Sea, the Pacific Ocean and other seas. A number of papers [6, 8, 11, 20] have suggested improvements in the theory and methods of marine pendulum surveys.

In 1955 a high-damping quartz gravimeter was used for gravity measurements on shipboard for the first time, by the All-Union Scientific Research Institute of Geophysics. A gravimeter of this type cannot react to the disturbance of the ship's acceleration, since the ship's rolling has a comparatively small

period. The elastic system with its high damping acts as a mechanical filter in relation to the ship's rolling and vibration, markedly diminishing these harmful effects. Experimental observations with a gravimeter mounted on gimbals have shown fully satisfactory agreement with the results of measurements using pendulums [2]. The damped gravimeter was used with great success in 1957 in the Sea of Okhotsk, where measurements were obtained, with a very small acceleration of the vessel, characterized by a root mean square deviation of ± 3 milligals — that is, possessing the accuracy of the very best marine pendulum measurements.

The possibility must be kept in mind, however, that systematic errors are introduced into measurements with a damping gravimeter, especially when the gravitational anomalies are of small extent or have high gradients or when the ship is moving rapidly. The adaptation of gravimeters for marine gravimetric surveying on board ships is one of the most urgent tasks of present-day scientific research. This was discussed in all its aspects in September, 1957, at Toronto (Canada), at the XI General Assembly of the International Union of Geodesy and Geophysics. At a special symposium on this question, it was revealed that gravimeters for observations on board ship were being developed in the U.S.S.R., the U.S.A., West Germany, Canada and Japan.

Great interest has been aroused by Graff's marine gravimeter (West Germany) for determining the acceleration of gravity on ships and submarines; the basic principle of this is strong damping of the system on metal springs. The gravimeter is mounted in a unique Cardanic suspension and furnished with a continuously-recording pen. According to an article in the American press, the Graff instrument was tested in 1957 off the east coast of America aboard an American Navy vessel. This ship had a gyroscope-stabilized platform on which the gravimeter was mounted. The measurements obtained with the Graff gravimeter agreed very closely with the data from pendulum observations made in the same place ten years earlier in a submarine. With the Graff gravimeter the measurements were made in a total of ten hours, as compared to the two days required in the submarine. A still greater advantage in time, in comparison with the pendulum method, has been gained by photographic processing of the readings. Measurements of the force of gravity using the Graff gravimeter will be made over a great part of the oceans by the research vessels of the Lamont Geological Observatory. There is also some information on the application of dry-land Worden quartz gravimeters in gravimetric surveys made around New Zealand in submarines.

The problem of systematic errors in observations made on ships, especially surface vessels, which are subjected to frequent and violent rolling and pitching, deserves special attention. On the Caspian Sea observations of the force of gravity have been made in the same areas, using both pendulums aboard ships and also bottom gravimeters. The readings of the latter may be considered free of systematic error. Comparison shows that observations on surface vessels consistently yield lower results. The most important effect is that of the vertical accelerations, as a result of which the difference between the gravimeter and pendulum determinations is about ± 20 milligals, and sometimes considerably more. Control observations with bottom gravimeters make it possible to introduce appropriate corrections into the results of gravimetric determinations made on board ships.

Gravimetric observations in the Pacific Ocean reveal an increase of 200 to 300 milligals in the Bouguer anomaly as one moves from the Sea of Okhotsk to the deep-water ocean basin [4]. This change in the gravitational anomaly is explained by an increase of some 35 kilometers in the thickness of the granitic-basaltic layer of the earth's crust beneath the Asiatic continent.

East of Kamchatka, gravitational anomalies trending parallel to the equator have been noted along the Aleutian island chain. The gravitational field in the Sea of Okhotsk is varied: here the maxima indicate the presence of parts of the crust that are of oceanic type, whereas the minima correspond to areas of present geosynclinal subsidence. There is a close connection between the gravitational anomalies of the Kurile-Kamchatka zone and the numerous earthquake foci, and also the chains of volcanos, in this zone.

An overall gravimetric survey of the Caspian Sea has produced a tectonic regionalization that agrees well with the results of aerial magnetic surveys. The field of weak positive and negative isometric gravitational anomalies corresponds to the area of the Paleozoic platform. It is separated from the deep minima of the Caucasus-Alpine geosyncline by a belt of maxima and large gradients. This is the very zone of deep faulting that also appears clearly on the map of the magnetic anomalies. A deep minimum unites the depressions of Azerbaydzhan and Turkmenia, but there is a difference between its eastern and western parts which corresponds to the results of bathymetric measurements and provides the basis for a tectonic diagram of the Apsheron spur [27]. Remotely controlled bottom gravimeters have been more and more widely used in recent years [17].

For detailed gravimetric work in the hallow-water zone of the sea in the U.S.S.R., everal systems of remote-control bottom nstruments and gravimeter repeaters on oard ship have been constructed. This quipment has been developed by the All-Jnion Scientific Research Institute of Geo-hysics. The instruments can be used on omparatively small vessels [15, 16]. The ottom gravimeter is mounted on gimbals and laced at the bottom of the sea. The greatest epth of water at which it is thus far possible o make observations is still no more than 00 meters. By means of the bottom gravi-neter, detailed operations have been carried ut in the vicinity of the Apsheron Peninsula nd the shores of Turkmenia (by the All-Jnion Scientific Research Institute of Geo-hysics and by the Azerbaydzhan Scientific esearch Institute for Oil Prospecting). With hese observations, it has been possible to race the continuations of the main tectonic lements of the Pribalkhash depression and he Apsheron Peninsula into the sea and to ocate the individual maxima which denote the enser cores of the chains of the diapirs of nud volcanos.

4. Marine electrical prospecting operations y the profile method were first begun in the ittoral zone of the Apsheron Peninsula in the 930's. In the shallow-depth zone of the sea, own to the 20-meter isobath line, were found reas of high conductivity corresponding to levations of the Produktivnaya series, which ontains mineralized waters [14]. Later seis-nic surveys and drilling have confirmed the esults of this electrical prospecting. Differ-ntial sounding profiles with considerably maller dispersion (4 - 16 m) were used in 950 to trace limestones occurring at small epths below the surface of the bottom near he shores of Dagestan (by the All-Union cientific Research Institute of Geophysics).

Beginning in 1954 in the Caspian Sea, lectrical prospecting has been carried out by he dipole sounding method. On one of the hips is a powerful generator which supplies dipole with direct current, the distance be-ween the electrodes being up to 500 meters. he second ship is connected to a receiving ipole. This ship has an oscillographic re-order which permits the current effect and he influence of telluric currents to be asses-ed. The distance between the two ships may e as much as several kilometers. Where he transmitting and receiving dipoles are ocated on the bottom of a basin, the results f the measurements are greatly affected by he conducting layer of sea-water above the ecording apparatus.

The theoretical curves of dipole electrical ounding indicate the possibility of making uch investigations at depths to 200 meters in the sea; at greater depths the resolving power of marine dipole electrical soundings is sharply decreased [1, 22, 24].

The placing of the receiver on different sides of the ship carrying the electrical gen-erator in dipole bilateral sounding has enabled geophysicists to determine the direction in which the electrical horizon of reference rises (Fig. 2).

Marine electrical prospecting can facilitate the surveying of the structures in a suitable geoelectrical profile and provide a basic orientation for more complex and expensive prospecting operations. But the chief value of marine electrical prospecting is that it can be used as an important supplement to the results of seismic prospecting. In the first place, the electrical resistance of the layers in the earth's crust beneath the sea gives some idea of their lithologic composi-tion. In the second place, electrical prospec-ting reveals the structure of areas in which seismic methods have produced no results, such as the crests (Fig. 3) of buried anti-clinal structures (Fig. 4). All these features make electrical prospecting a useful tool in the complex of marine geophysical prospecting methods.

5. The most valuable tool in studying the folding in sedimentary rocks in marine areas and in searching for anticlinal structures that are likely locations for the accumulation of oil and gas is seismic prospecting based on the principle of reflected waves [25]. In marine seismic prospecting the seismograph is suspended, in hermetically sealed casings, at some distance from the bottom of the sea and is connected by conductors to the seismic recording station on board ship. Seismic operations using reflected waves were begun around the Apsheron Peninsula in 1941. Since then seismic methods have been used success-fully to study the littoral zone of the Caspian Sea in the areas of the Apsheron and Baku archipelagos and along the shores of Dagestan and Turkmenia. By means of seismic marine prospecting, a number of anticlinal structures have been found in the littoral zone of the Caspian which are suitable areas for explora-tory drilling for oil and gas [28].

The application of the seismic reflected wave method in the sea has encountered a number of specific obstacles. Explosions at great depths lead to the formation of a pulsing bubble of gas and thus to the creation of repeated shocks. To avoid the spreading of explosion impulses by repeated shocks, it becomes necessary to suspend the charges from floats and explode them at a depth of 0.5 to 2 meters. Then the gas bubble, after the explosion, pushes its way through the comparatively small depth of water over the

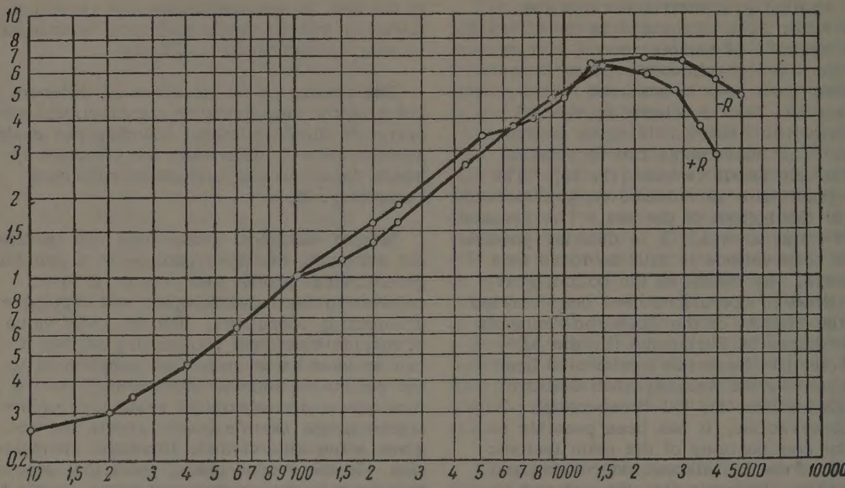

FIGURE 2. A typical curve of bilateral dipole sounding in the Caspian Sea: raising (R+) and lowering (R-) of the high-resistance horizon.

explosive charge and emerges into the atmosphere. The smaller the charge, the nearer the surface it must be exploded.

Explosion of the charge at the surface itself, however, decreases the energy of the explosion impulses and necessitates an increase in the weight of the charge to several kilograms. Another difficulty is caused by irregular high-frequency oscillations, which are especially intense in certain parts of the sea. These oscillations, whose frequency is as high as 50 to 200 cycles, appear directly after the first shocks and die out very slowly. By analogy with acoustical phenomena, they have been called reverberation interference. Such reverberation interferences greatly hinder the reception of reflections from the levels that are being studied.

Especially intense marine seismic reverberations arise when the basin is composed of dense rocks with a high reflectance. It has been shown experimentally that in the

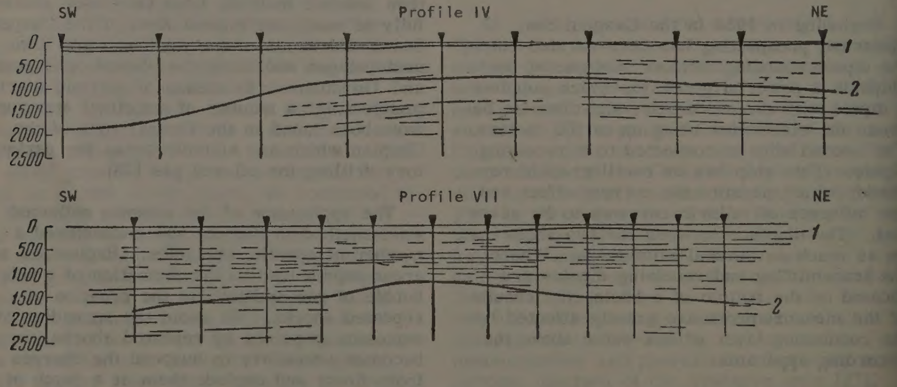

FIGURE 3. Results of a study of one of the anticlinal structures on the Azerbaydzhan shore of the Caspian Sea (1) by the seismic method of reflected waves and (2) by the electrical prospecting method of dipole sounding.

icinity of the explosion, high-frequency seis- iic reverberation arises from the repeated eflection of elastic waves by the boundaries etween air and water and bottom and water. loreover at some distance from the explo- ion, reverberation may also arise as a result f scattering of the elastic waves at the bound- ries between these media [18].

Frequency analysis of the marine seismic everberation has revealed that it has two omponents with different frequencies. The equencies of the reverberation differ from iose of the reflected signal. The harmful ffects of seismic reverberation interferences ave been largely diminished by means of oecial filters in the seismic amplifiers and y the grouping of the seismic receivers.

Indirect magnetic recording has been used kperimentally in marine seismic prospecting ith reflected waves. The electrical impulses om the seismic channels are recorded on magnetic tape. The magnetic recording is done with amplifiers which pass uniformly the entire range of operating frequencies. Then the magnetic record is used to reproduce the recorded vibrations with an arbitrary distortion in the laboratory. This recording is made with amplifiers having different frequency characteristics. In view of the difficulty of obtaining seismic data at sea, especially under identical explosion conditions, the use of magnetic recording under marine conditions holds great promise. Experimental work with magnetic recording has produced results that yield nothing in accuracy to those obtained by the usual means (Fig. 4).

Piezoelectric crystal seismic receivers were first used in marine seismic prospecting in 1954. Because of the small size and weight of such receivers, they are easily placed in a vinyl chloride hose filled with oil. The specific gravity of the hose and oil is approximately equal to that of sea water. The lead

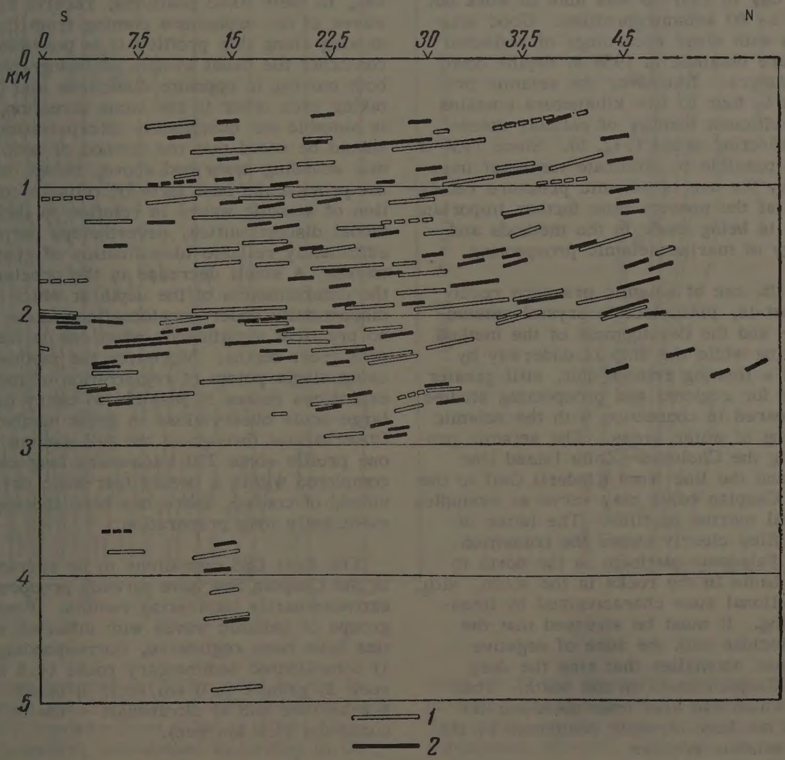

FIGURE 4. Seismic sections in the Caspian Sea obtained in 1955 (1) with the usual 26-channel SS-26-51D station and (2) with a 12-channel station for intermediate magnetic recording.

wires are also placed in the hose. By spacing the piezoelectric crystal receivers along the length of the hose, it is easy to group the seismographs properly so as to obtain the best record of the reflected waves. The hose, with its 12- to 24-channel crystal receivers, is towed at a certain depth with the seismic instruments behind the ship and records the explosions as the ship is moving [7, 21].

Other types of floating seismographic remote units mounted in an air-filled canvas hose or on floats were developed in Baku in 1957-1958. These used both piezoelectric crystal receivers and a newly developed seismograph whose design is based on the use of a filtered electrical potential.

The existence of various kinds of floating and towed remote units has facilitated expansion of the scale of marine seismic reflected-wave prospecting and its extension into the deeper parts of the sea. On the Caspian Sea, for example, a seismic party of the All-Union Scientific Research Institute of Geophysics in a single day in 1957-58 was able to work out as many as 60 seismic profiles. Good seismograms with clear recordings of reflected waves were obtained in 1958 at depths down to 600 meters. Moreover the seismic profile down to four to five kilometers contains a quite sufficient number of reliably determined reflecting areas (Fig. 5). Since 1958 it has been possible to eliminate the chief interference by the use of seismic pressure receivers, and at the present time further important progress is being made in the methods and technology of marine seismic prospecting.

After the use of seismic pressure receivers — that is, piezoelectric crystal seismographs — and the development of the method of operating while the ship is underway by means of a floating remote unit, still greater prospects for regional and prospecting studies have appeared in connection with the seismic prospecting of water areas. The seismic profiles along the Cheleken—Zhila Island line (Fig. 6) and the line from Kinderli Gulf to the southern Caspian basin may serve as examples of regional marine profiles. The latter of these profiles clearly shows the transition from the Paleozoic platform in the north to the deep basin in the rocks in the south, with the transitional zone characterized by intensive folding. It must be stressed that the latter coincides with the zone of negative gravitational anomalies that ring the deep southern Caspian basin on the north. This feature, which had also been noted earlier [26], has not been strongly confirmed by the regional seismic profiles.

The study of the depth of the crystalline basement and the deeper layers of the earth's crust makes use of a method, elaborated in the U.S.S.R. by the Institute of Terrestrial Physics of the Academy of Sciences, that combines the refracted-wave method and that of deep seismic sounding (DSS). DSS operations to study the depth of occurrence of the basic surfaces within the earth's crust, down to the Mohorovicic discontinuity (the M surface), were carried out in 1956 in the Caspian Sea and in 1957-1958 in the Pacific Ocean and the Sea of Okhotsk, in the zone of transition between the ocean and the continent of Asia. In the development of DSS in the Caspian Sea, it was established that the most rational method of marine seismic sounding was to use movable points of explosion and to register the seismic waves with solitary hydrophones on several (two to four) ships located along the seismic profile [3].

The method of movable explosions and fixed points of observation is equivalent to the method of movable observation stations and fixed points of explosion. For this reason, when the registering ships are positioned at intervals along the seismic profile and, in their fixed positions, receive the waves of the explosions coming from the ship moving along this profile, it is possible to construct the usual system of hodographs, both moving in opposite directions and overtaking each other in the same direction, that is suitable for quantitative interpretation. It should be noted that the method of deep seismic sounding described above, though it does not provide the best form of reliable correlation of seismic waves in relation to the individual discontinuities, nevertheless permits a sufficiently reliable identification of groups of waves. A small decrease in the precision of the determination of the depth at which the discontinuity under consideration occurs is of no practical significance when one is dealing with great depths. Moreover the method of using single points of registration of movable explosions makes it possible to carry out large-scale observations in great number. Observations throughout the full system of one profile some 250 kilometers long can be completed within a twenty-four-hour day, provided, of course, there has been thorough and sufficiently long preparation.

The first DSS operations to be carried out in the Caspian Sea have already produced extraordinarily interesting results. Four groups of seismic waves with different velocities have been registered, corresponding to: 1) consolidated sedimentary rocks (4.8 km/sec); 2) granite (6.0 km/sec); 3) basalt 6.6 km/sec and 4) ultrabasalt — the M discontinuity (8.0 km/sec).

On the seismic profile, the boundary between the Paleozoic platform and the geosynclinal subsidence of Alpine age may be traced easily by the increase in the total thickness of

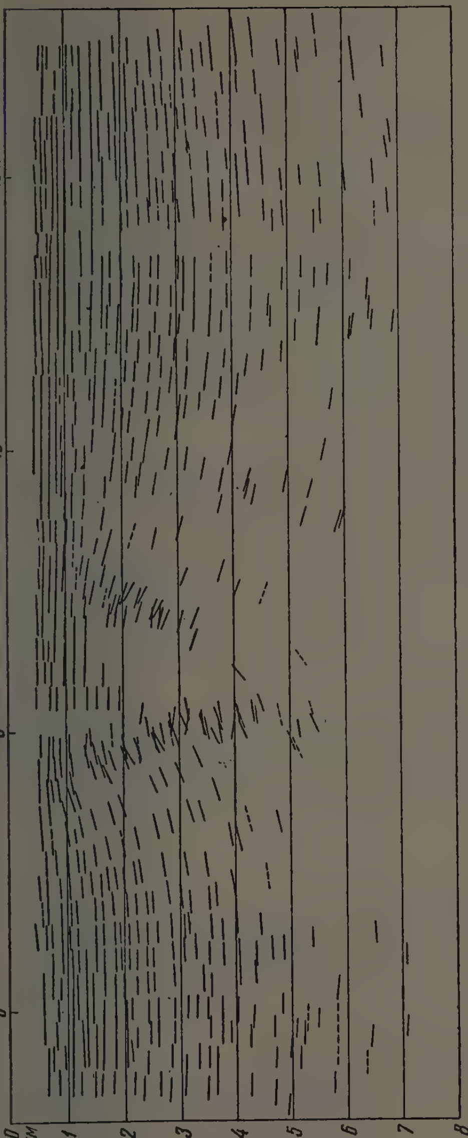

FIGURE 5. A seismic profile worked out with a piezoelectric remote unit.

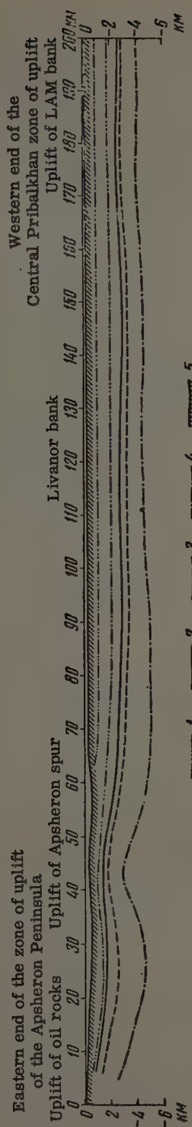

FIGURE 6. Diagram of the geologic structure of the Apsheron threshold, according to data from a seismic profile of the Cheleken-petroleum rocks: 1 -- at Apsheron and Akchagyl; 2 -- near the top of the Produktivnaya series (at Cheleken, redbed deposits); 3 -- near the top of the Sabunchinskaya suite, 4 -- near the top of the Podkirmakinskaya suite (PK), 5 -- bottom of the sea.

:he crust from 35 to 42 km, and by the in-crease in the thickness of unconsolidated sedi-nentary deposits from 1 km to 10-11 km. This boundary, established according to DSS, was found to coincide with the boundary seen n the results of gravimetric and aerial mag-netic operations. The Paleozoic crystalline basement sinks in the transitional zone to a depth of 20 km or more, and then disappears entirely, giving way to the basaltic layer. The latter, in the area of the geosynclinal subsidence, directly underlies the consolidated sedimentary rocks, and rises sharply in the direction of Talysh — toward the Talysh-Vandam gravitational maximum (Fig. 7). Even more interesting results were obtained in

1957-1958 in the Pacific Ocean, where the depths of the discontinuities within the earth's crust are much more sharply differentiated and much more clearly reflected. Accumulation and processing of data obtained by DSS in the Pacific Ocean is continuing at the present time.

the U.S.S.R. Academy of Sciences must be continued and expanded.

One important task is the drawing together of marine geological and geophysical research in solving a number of problems, beginning with the study of the bottom sediments and

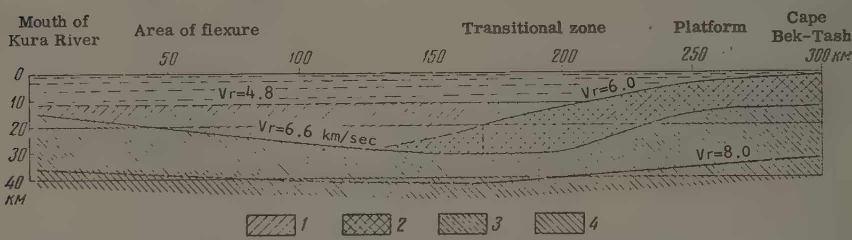

FIGURE 7. Diagrammatic section through the earth's crust in the central part of the Caspian Sea from the mouth of the Kura River (SW) to Cape Bek-Tash (NE):

1 -- Consolidated sedimentary rocks; 2 -- "granitic" layer, 3 -- basaltic layer; 4 -- substratum under the Mohorovicic discontinuity.

From the review in this article it is clear what great opportunities are now offered for marine seismic research as a result of the intensification of the efforts of Soviet geophysicists in the past few years. Great strides in this field have also been made in other countries, notably the U.S.A. and England [10]. Nevertheless marine seismic investigation must in the future be further improved and developed, and also properly combined with other geophysical observations.

6. Marine geophysical prospecting requires the carrying out of a number of supplementary hydrographical tasks. Regional geophysical investigations, especially at great depth, require the use of an echo sounding device. Echo sounding with oscillograph recording of the reflected impulses is also useful in determining the nature of the rocks at the bottom of the sea. The ship's coordinates in making geophysical measurements in the open sea are determined by radiogeodesic means.

7. At the present time the theory and the practice of marine geology in all of its growing domain urgently requires geophysical investigation of the continental shelf and the oceans. There must be a further elaboration of the theory, methods and technology of combined marine geophysical work. The study of the continental shelf (to the depth of 200 to 250 meters) is in need of considerably greater detail and precision. The marine geophysical investigations of the scientific expeditions of

ending with the subdivision of the entire thickness of the earth's crust into its basic complexes. Geophysical methods of investigation must be given the widest and most systematic application in marine geology. This will greatly expand both the possibilities and the effectiveness of the geological study of the seas.

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MORPHOLOGICAL CLASSIFICATION OF BEDDING IN SEDIMENTARY ROCKS[1]

by

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1. GENERAL REMARKS

The need to create a morphological classi-:ation of bedding has been stressed repeat-lly by many investigators, but such a classi-:ation in the full sense of the word has up the present time not existed. Various ithors at different times have proposed 'oupings and schemes for categorizing the pes of bedding textures, usually those which 'e either most common or best known to the ırticular author. Type categories of bedding :cording to the shape have been suggested by Walther, K. Andrée, W. Hoppe, Yu. A. ıemchuzhnikov, Ye. P. Bruns and others [4, 16, 17, 25].

The systems proposed for categorizing the pes of bedding have the following defects: the first place, not one of them encom-ısses the whole variety of bedding textures; the second place, some of them are con-:rned mainly with the types of stratification, ith which certain types of layering[2] are also ımbined; that is, a common categorization is ven for two different phenomena; in the third ace, the categories either inconsistently llow different principles (J. Walther, W. ɔppe) or else the types themselves are stinguished according to a single principle ıt the subdivisions within them are arbitrary , 5]; in the fourth place, in a number of ıses the boundaries between the types or the ore detailed subdivisions are insufficiently ear, so that the same instance of bedding ay be assigned to different groups.

In one of the latest works, in Andersen's :heme as cited by Pettijohn [24], the types ' bedding are given according to their form, ısed on the dynamics of the sedimentary 'ocess, but these are far from exhausting all the types of bedding; the same criticism applies to the classification of cross bedding suggested by E. D. McKee and G. W. Weir on the basis of morphological criteria, and to the number of particular groupings of bedding by N. B. Vassoyevich [6-9].

The present author has suggested a type classification of bedding according to form and dimensions, with a further subdivision based on morphological indices: the latter will to a large degree be the basis of the classification proposed in this article.

Besides morphological, some authors have suggested genetic classifications of bedding, but these too have included not all, but only certain of the genetic types [10, 12-14]. Moreover the absence, in the basis of these classifications, of clearly characterized morphological types led to the situation in which bedding assigned to one genetic type might be encountered in others as well. As a result, some doubt has been thrown on the very possibility of determining the origin of a rock by studying its bedding structure, on the basis of the supposition that the same forms (or, more likely, similar forms) could be encountered under different conditions of sedimentation.

Investigators have also come to this negative conclusion for the reason that the bedding is usually defined too schematically and primitively (for example, very often in the description of a rock it is merely noted that the bedding is "cross-bedded").

Classifications of bedding that are based on facies — that is, on the mechanism of their formation, the causes of their origin, etc. — are not the fruits of observation but merely the conclusion of the investigator, based on whatever treatment of the criteria he has developed. If these classifications are to be correct, they must inevitably be preceded by a morphological classification, since only the latter can be based for accurate identification and measurement of the indications visible directly in the rock, and on a

[1] Morfologicheskaya klassifikatsiya sloistosti osa-ɔchnykh porod.

[2] The difference between these concepts will be ɛfined below.

systematic grouping of these objective criteria independent of the subjective viewpoints of the various investigators.

Thus a morphological classification, although it plays a supplementary role, is entirely necessary for correct genetic conclusions. Its existence guarantees that the determination of the bedding will be objective and accurate, that the terminology will be consistent and the description of the types uniform, so that factual data on different objects and from different authors can be compared.

If a morphological classification is to fulfill its purpose, the morphological criterion on which it is based must be the most important one from the standpoint of the formation of the deposit (the mechanism of formation and the facies conditions under which the sediment was deposited). Such criteria must, on the one hand, be common to all elements in a grouping of bedding textures and, on the other hand, must reflect the differences between the bedding features of different groups. The morphological classification should also be constructed according to a single principle that will encompass all possible types of bedding in rocks; at the same time it should be as simple as possible and sufficiently easy to apply in the actual conduct of geologic investigations.

2. THE ELEMENTS OF BEDDING TEXTURE AND THEIR DEFINITIONS

Before analyzing the criteria for bedding in rocks, let us dwell briefly on the choice of terms and the definitions of the main elements of bedding textures, which are bedding units of different scales of magnitude: strata, beds, layers, packs of layers, series of layers and groups of series, and also surfaces of separation between them, or "seams" — stratum, bed, series, layer seams, etc.

The fundamental unit of a sedimentary series is the bed, which is usually defined as a geologic body, more or less uniform in composition, separated from the neighboring beds by bedding planes. Hence the criteria for distinguishing a bed will be these: 1) greater or lesser internal homogeneity, 2) difference from the adjacent beds, 3) the presence of surfaces of separation or boundaries between the beds. These three criteria may be manifested to different degrees, or some one of them might even be lacking, but in general the distinguishing of a bed will always be associated with some change in the conditions of sedimentary accumulation, even though within a single facies.

The concept of a "bed" would appear to be clear to everyone. As M.S. Shvetsov [15] has quite properly pointed out, however, the problem of distinguishing beds is far from a simple one, and its solution often depends on the distinctness and the scale of the particular phenomenon itself and on the requirements made of the investigator by the degree of detail with which he is studying a sedimentary series. If the transitions and boundaries between the beds are blurred, the distinction of the beds will be somewhat tentative, and will also in considerable measure be determined by the particular investigator's purposes.

The bed is the basic element in the bedding structure of sedimentary rocks. The word "stratum" is frequently used as a synonym for bed, but this is not entirely true. It would be more proper to consider strata as beds or groups of beds whose differences are due to changes in facies conditions, so that adjacent strata will always have different facies. Directly at the outcrop it is often hard to decide whether one is dealing with a bed or a stratum, except for those cases in which it is characterized by some mineral that distinguishes it from the surrounding rocks. Apparently for this reason the word "stratum" is frequently used in connection with minerals of economic value (stratum of coal, phosphorites, etc.). A stratum may consist of several beds or be the equivalent of one bed, but it cannot be part of a bed. The alternation of beds or strata creates the texture of sedimentary rocks.

On the other hand, beds of various rocks in turn have an internal layered texture, for which special terms are needed. The basic unit of layering, in the sense of the rock's internal texture, is the layer.

Although the concepts "layer" and "bed" have been used already, they have not been sufficiently clearly distinguished, and the difference between them has been for the greater part related to size (a layer being considered a small bed). A clear distinction between them on the basis of some essential difference was first given by N.B. Vassoyevich (1948), who pointed out the differences between the formation of bed and layer. He also suggested the term "layering" (derived from the word "layer" — sloychatest' and sleyek respectively in Russian), to distinguish it from the phenomenon of proper bedding or stratification in a rocks. This term will be used here whenever it is necessary to stress the actual layered structure of a rock. Table 1 cites a number of criteria of the differences between a layer and a bed; points 2, 4, 5, 7, 8 and 10 are taken from N.B. Vassoyevich [9] with a few changes. The basic criterion is the fourth.

Table 1

The difference between the indices of bed and layer

Indices[a]		Units of stratification	
		bed	layer
1. Similarity of the combined units and their repetition (the main index of difference)		Adjacent beds always differ (may be repeated in a cyclical section)	Adjacent layers are of a single type, with numerous repetitions
Parameters	2. Thickness	Varying	Small (millimeters or centimeters)
	3. Area (lateral extent)	Great	Small in cross and rippled bedding; may vary in horizontal bedding
	4. Primary inclination	Little or none (exceptions rare)	Reaches 30° - 40° in cross and rippled bedding; lacking in horizontal bedding
Structure	5. Internal texture	Bed may consist of layers (may be layered)	The layer is the smallest unit of stratification (the lowest form of individual deposit)
	6. Presence of interlayers	May be present	None
7. Association with rock's lithology		Bed encompasses a single rock type	Layers may appear within a single rock type
Time of formation	8. Absolute	Long (years or thousands of years, more rarely seasons)	Short (sometimes hours or days, frequently seasons)
	9. Relative	More frequently instantaneous formation, but may occur at various times	Formation always instantaneous
10. Conditions of formation		Conditions of sedimentary accumulation change, resulting in formation of beds	Overall conditions of sedimentation unchanged; formation of layers determined by fluctuation of the sediment-forming factors (sometimes showing a definite tendency)
Appearance		Stratification in sedimentary rock series	Stratification in sedimentary rocks (or layering)

[a]Indices 2, 4, 5, 7, 8, and 10 taken from N.B. Vassoyevich [9] with some changes.

Nevertheless, although the difference between bedding and layering in the case of cross and rippled bedding is clearly visible, in relation to the units of bedding in the general line of stratification, in the case of horizontal bedding this criterion is lacking, and the distinction between them at once becomes difficult to perceive (especially if the beds are thin), as N.B. Vassoyevich has also pointed out [9]. This is, however, a very important problem, since it is intimately associated with the causes and mechanism of formation of beds and layers. On the other hand, it is incorrect to distinguish between the terms on the principle of determining the causes, since such a determination is the conclusion of each individual investigator, which is often very subjective. More objective criteria are needed which can be discovered directly in the rock. Analysis of the data shows that one such determining criterion is the nature of the alternation of layering units, which depends on the mechanism of their formation. The formation of beds is associated with change in the sediment-forming factors, owing to various causes. The formation of layers is determined by a regular (rhythmic) and frequent but small variation in the sediment-forming factors, always under the same facies conditions of sediment accumulation (as, for example, seasonal changes in the composition of the layers, changes in the momentary rates of flow, tidal ebb and flow, etc.).

Thus if one proceeds from the mechanism of the formation of layering, a layer is the smallest elementary unit of the bedding structure of a rock, repeated cyclically in the section (as determined by the repeated periodic fluctuations of the sediment-forming factors). A layer is usually of small thickness (no more than a few centimeters) and, in the case of cross and rippled bedding, of small lateral extent.

On the other hand, if one sees even very thin units of stratification which are not a repetition, but represent a change in the composition of the rock, these are beds and not layers (as in deep-water sediments, where the thickness of the beds is very small). But if one is confronted with a repetition of similar beds related to changes in the facies conditions, usually numerous and on a larger scale, this is also not layering, but a particular type of bedding in the rock known as rhythmic or cyclical bedding. The sedimentation cycle usually encompasses several beds, which in turn have internal layered textures, whereas a layer has no internal layered texture.

All these criteria permit a clear and reliable distinction between the bedding in a sedimentary series (stratification) and the internal texture of the rock, which is layering.

A bed may consist directly of layers, but in the majority of cases the layers form either series of layers or packs, which in turn make up the bed. Sometimes series of layers form groups of series. In certain complex types of bedding, the layers form packs of layers, the packs form series and the series form the bed. All these units of layering, like the layers themselves, are elements in the composition of the internal texture of rocks.

A <u>pack of layers</u> is a group of layers associated with a definite trend or tendency in the change of thickness or composition of the layers, analogous to the tendency of the change in the adjacent groups. In other words, a pack is a particular rhythm in the layered texture in which the layers change to and fro, and bedding represented by packs is rhythmic or cyclical. Pack structure is very characteristic of horizontal bedding. A pack may contain a minimum of two layers; in such a case it may be described by the well known term "varve". Hence varve bedding is a particular case of horizontal cyclical bedding.

A <u>series of layers</u> is a group of layers of a single type, alike in structure, composition, thickness and mode of occurrence. The layers in a series may be either parallel or similar, since they are formed under similar conditions of sedimentation and under the same dynamic conditions in the medium of deposition.

The difference between a series and a pack is that a pack contains layers of different kinds. The formation of a pack is determined by the same fluctuation in the sediment-forming factors as in the formation of a series, but on a different (secondary) order. The series are combined like layers, and their occurrence is due to the formation and migration of shapes in the surface part of the deposits (sand bars, ripples, etc.).

In certain cases one distinguishes a group of series — that is, a number of series associated with each other by some kind of change from series to series; frequently this change will exhibit a regular tendence (within the group of series). All these elements of bedding structure are shown diagrammatically in Figure 1.

In conclusion, some mention must be made of the term "layering", which was suggested by N.B. Vassoyevich and which, in his original expression, means "stratification without beds" when the bedding units are not identified but the character of the stratification is nevertheless visible in the disposition of either

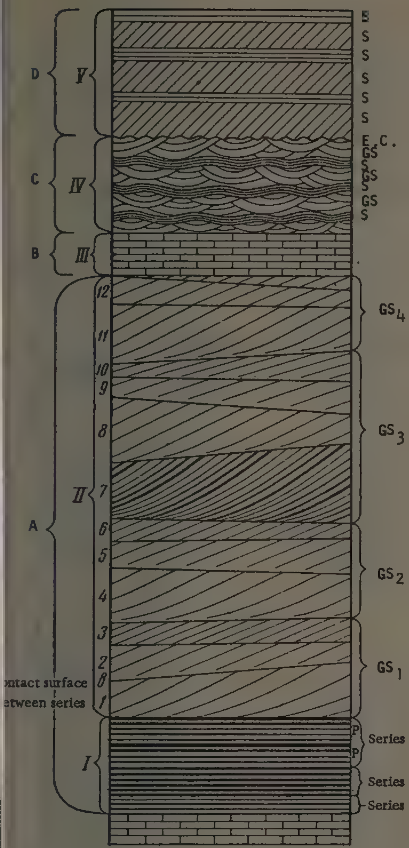

FIGURE 1. Diagram showing the basic elements of stratification:

A, B, C, D -- strata; I, II, III, IV, V -- beds; S -- series; P -- packs; GS -- groups of series; E.C. -- erosional contact surface;

A -- stratum of sandstone (between two limestone strata) consisting of two beds with different textures: I -- horizontally bedded sandstone containing three horizontal series, the upper series in turn consisting of packs of layers; II -- cross bedded sandstone (1-12 are series of slantwise layers); GS_1, GS_2 etc. are groups of series of slantwise layers, in each of which the thickness of the series decreases from bottom to top; in the third group of series the lower oblique layered series is composed of packs of oblique layers.

Strata B, C and D contain one bed each (are equivalent to a single bed). Beds IV and V have compound mixed layering: IV is gently rippled with trough-like ripples; V is diagonal (alternating horizontal and oblique series).

e anisometric particles that compose the ck or inclusions in the rock (pebbles, con- etions, organic remains). This term very ccessfully expresses the indeterminate ture of the stratification.

The character of the bedding (layering) in rock is very intimately associated with the rmation of the deposit of sediments, which turn determines the difference in the dices and the details of structure that per- it one to distinguish between bedding of dif- rent facies environments, although they are nilar in form.

In any deposits — clastogenic, chemogenic, biogenic — the bedding is formed either rectly in the settling of the sedimentary aterial or as a result of its redistribution er deposition. Direct settlement as a rule s produced horizontal bedding or bedding at reflects the relief of the bottom. The stratification in it is more often determined by external factors. Bedding formed by redistribution of the material shows greater variety. In the case of clastic sediments, the displacement of the material along the bottom by currents and wave action produces different types of bedding — cross bedding, cross-and-rippled bedding, rippled bedding, slanted rippled bedding, and a special type of horizontal sorted bedding. Redistribution of the material as a result of chemical processes in diagenesis results in either a special diagenetic stratification which may, somewhat tentatively, be considered as bedding, or else produces false bedding. Biogenic sediments have either horizontal bedding or special forms of bedding determined by the specific growth of certain live organisms. Moreover the accumulated remains of organisms, or mineral grains that have been chemically precipitated, may be redistributed through the action of the physical and mechanical factors of bedding formation; in such a case they are subject to the same laws as clastic deposits and form the same types of bedding.

3. SPECIFIC FEATURES OF BEDDING

The morphological classification proposed here is based on indices including both layers and series of layers. These determine: the morphology (shape and interrelationship) of the layers and series, their internal structure, the nature of the boundaries between them and the different means of grouping them. In addition, certain indices have a quantitative expression: the determination of the thickness and angles of inclination of the

Table 2
Indices of layers in the main types of bedding

Layer indices			Cross bedding	Sketch diagram	Rippled bedding	Sketch diagram	Horizontal bedding	Sketch diagram
Morphology	1. Shape of layers	Bent	Straight line		Symmetrical: Concave (trough-shaped)			
			Concave at base		a) Concavo-convex			
			Concave uniformly		b) Convex (rare)		Regular	
			S-shaped (concavo-convex)		Asymmetrical: Concave		Irregular	
			Convex (rare)		Concavo-convex			
					Convex			
	2. Relationship between layers in the series		Parallel		Parallel		Always parallel to each other and to base of series	
			Converging at bottom		Converging toward base of series			
			Converging at top and bottom		Converging toward sides of series			
			Converging at top					
			Branching a) from common point					
			Branching b) successively					
Composition	3. Texture of layer		Uniform		Uniform		Uniform	
			Sorted		Sorted		Sorted	
			Two members		Two members		Two members	
			Heterogeneous		Heterogeneous		Heterogeneous	
	4. Inclusions and their mode of occurrence	Nature of inclusions	Pebbles		Same as in cross bedding			
			Coarser material					
			Concretions					
			Plant remains					
			Fauna					
			Individual minerals: mica					
			Individual minerals: pyrite					
		Occurrence	At bottom of layer and parallel to it		At bottom of layer		At bottom of layer	
			In lower part of layer in series		At lower part of trough			
			At top of layer and parallel to it		At top of layer		At top of layer	
			Scattered irregularly		Irregularly scattered		Irregularly scattered	
Disposition	5. Distribution of layers in series and combinations of series		Evenly (regularly) distributed		Regular		Regular	
			Rhythmic (forming packs of layers)		Rhythmic		Rhythmic	
			Irregular (uneven and without order)		Irregular		Irregular	
Quantitative indices (determined by measurement)	6. Thickness of layers		Very thick — more than 1 m		Same as for cross bedding			
			Thick — 1 m - 10 cm					
			Very large — 10 cm - 5 cm					
			Large — 5 cm - 2 cm					
			Medium (average) — 2 cm - 5 mm					
			Thin — 5 mm - 1 mm					
			Very thin (Microscopic) — less than 1 mm					
	7. Angle of inclination		Steep — more than 30°		Determined by ripple index (if l:h is greater, angle is smaller) or by magnitudes of l, ∂n and ∂k		None	
			Medium — 30°-20°					
			Gentle — less than 20°					
		Change in inclination of layers in series	Uniform		Not determined			
			Increasing					
			Decreasing					

*In addition to the category, one must take into account the actual thickness, its limits of fluctuation and predominant magnitude.

bedding elements, as well as the ripple indices and the indices of their asymmetry (Tables 2 and 3).

The chief index for the determination of bedding in rocks is the attitude of the layers relative to the general stratification — crosswise, wave-like or horizontal. This index also determines the basic types of bedding, corresponding to the environment of the medium of sedimentation: current, wave action or immobility.

Table 3

Indices of series of layers in the main types of bedding

Series indices			Bedding: Cross bedding	Sketch diagram	Rippled bedding	Sketch diagram	Horizontal bedding	Sketch diagram
Morphology	1. Shape of contact seams between series		Straight		Symmetrical: Concave (trough-shaped)		Straight: Regular	
			Bent: Concave		Symmetrical: Concavo-convex a) b)			
			Bent: Concavo-convex		Symmetrical: Convex			
			Bent: Convex (rare)		Asymmetrical: Concave		Straight: Irregular	
					Asymmetrical: Concavo-convex			
					Asymmetrical: Convex			
	2. Relationship between series		Parallel		Parallel		Always parallel	
			Non-parallel, intersecting at small angles (incl. wedge-shaped)		Non-parallel, at small angles — displaced: regularly spaced a); irregularly spaced b)			
			Non-parallel, intersecting at great angles (incl. criss-crossed)		Non-parallel at large angles (criss-crossed)			
	3. Structure of series	a) direction of layers in adjacent series	Same direction		Change in direction of layers in rippled bedding not observed; in case of oblique rippled bedding may be: in same direction, or irregularly in different directions.		None	
			Different directions: regularly					
			Different directions: irregularly					
Composition		b) change in material of series	Homogeneous		Same as in cross bedding			
			Sorted					
			Tied to layers					
	4. Inclusions and their mode of occurrence		Same as for layers; may be: at top of series		Same as in cross bedding, but rarely at top of series		Same as in cross bedding	
			at middle of series					
			at bottom of series					
Disposition	5. Distribution of series in bed or stratum	a) change in dimensions of series	Uniform dimensions		Same as in cross bedding, but more rarely observable		a) and b) same as in cross bedding c) does not occur	
			Regularly changing					
			Non-uniform (irregularly changing)					
		b) change in composition of series	Uniform composition					
			Regularly changing					
			Non-uniform (irregularly changing)					
		c) change of inclination of layers within series*	Becoming steeper toward top					
			Becoming gentler toward top					
Quantitative indices (determined by measurement)	6. Thickness and indices		Thickness of series measured in: Very thick — meters; Thick — decimeters; Thin — centimeters; Very thin — millimeters		To be determined: 1) thickness of series (T) — classification same as in cross bedding; 2) length of ripple — l; 3) height of ripple — h; 4) ripple index — l:h; 5) index of asymmetry — ∂n:∂k		If series are discernible in horizontal layering, classification of series is same as in cross bedding; if there are no series and layers form a bed (series = bed), classification of horizontal layering according to thickness is not given.	
	7. Inclination of series relative to overall bedding planes		Horizontal (parallel to bedding)		Parallel to bedding		None	
			Inclined predominantly in one direction		Inclined at an angle to bedding			
			Inclined in various directions					

* If the greatest angle of inclination of the layers is in one plane, this point indicates a change in the rate of flow; if in different planes, a change in the direction of flow.

The second determining index is the thickness of the series, closely connected with the scale of the phenomenon: the force of the current or wave action, or in the case of an undisturbed medium, the length of time in which the bed accumulates and the quantity of sedimentary material. The thickness of the layers generally is not great and changes little. The changes depend not on the facies, but on the granulometric composition of the rock.

Generally speaking, the thickness is an

index that can be perceived by the naked eye and is easily determined by measurement. For this reason bedding has long been classified by the thickness of the beds, and it would appear that this index should be completely determined and its terminology fully established. In reality, however, this is not the case: the determinations of bedding by thickness are not at all coordinated (see Table 4, last section), not to mention the fact that it is usually not made clear whether it is the thickness of beds or layers that is being determined.

For the sake of uniformity in terms, on the one hand, and to differentiate between determinations of beds and layers on the other hand, a classification of bedding by thickness is presented (Table 4). This is based on a decimal system, using the intervals 1 millimeter, 1 centimeter, 10 centimeters and 1 meter. Within these limits, terms of one type are given: bedding in a stratigraphic series (stratification) according to the thickness of the beds, and bedding in a rock (layering) according to the thickness of the series of layers. These are distinct from thickness terms suggested for layers; the latter are given more detailed gradations from 1 millimeter to 10 centimeters (by intervals of 1-5 mm, 5 mm - 2 cm, 2-5 cm and 5-10 cm). Finally, terms for stratification are suggested in the case of the presence of sharp boundaries between the beds or strata. It must, of course, be said that this classification must in no case be approached mechanically. For example, bedding with series thickness from 8 to 12 centimeters is, naturally, called "fine" and not "alternating fine and coarse" (with an indication, of course, that the bed thickness goes up to 12 cm). In general it may be said that if the layering is very coarse, the thickness of the series will be measured in meters, if it is coarse in decimeters, if it is fine in centimeters, and if it is very fine in millimeters.

Measurement of the angles of inclination is most essential in the case of cross bedding; usually the maximum inclination is determined. The angles of inclination reflect the intensity and the nature of the movement in the medium of deposition (aqueous or eolian). Measurement of the azimuths of the dip angles of the layers aids in establishing the direction in which the sedimentary material was transported.

In the case of rippled bedding and rippled cross bedding, one must determine the ripple index — the relationship between the length of the ripple and its height.[3] This is also the index of the facies environment. If the bedding is asymmetrical, one must also determine the index of asymmetry, which is the ratio of the length of the gentle and long slope of the ripple swell to the length of its short, steep slope ($\partial n:\partial k$). This quantity differs somewhat from the generally used "second index" or "degree of asymmetry", determined as the ratio of the horizontal projection of the gentle slope to that of the steep slope ($l_2:l_1$). But the latter ratio remains unchanged even with a change in the height of the ripple, whereas the asymmetry of the ripple does change under these conditions: the ratio ∂n and ∂k are easy to determine in any plane, both in the vertical section and in the plane of stratification, but l_2 and l_1 can be determined accurately only in the vertical section. Finally, if one knows the values of l, ∂n and ∂k, by a simple calculation one may also find the angle of inclination of the layers and the shape of the ripple.

Analysis of all these elements, of the mechanism of their formation and the relationship of each index to the various conditions under which the sediment is formed[4] allows us to establish the morphological classification of the bedding textures of sedimentary rocks that is presented below. Although this is a classification according to the form of the bedding, it is constructed in such a manner that each of the types in it corresponds to a specific mechanism of formation of the deposit.

4. MORPHOLOGICAL CLASSIFICATION OF BEDDING

It has been mentioned that three main types of bedding are distinguished — cross bedding, rippled bedding and horizontal bedding. Cross bedding has the layers inclined at an angle to the boundary of the series of layers; and the latter in turn are often inclined toward the bedding planes. Such bedding is usually formed by currents. The layers in rippled bedding form waves (or parts of waves) parallel to the base of the series. These are formed by waves, or else represent the layering of wave and current ripples. The layers in horizontal bedding are horizontal and parallel both to the base of the series and to the overall bedding planes. They indicate deposition of beds at the bottom of the basin in an immobile medium.

Moreover two intermediate types of bedding are distinguished — cross-rippled and gently rippled. Cross-rippled bedding is characterized by rippled contact surfaces between the

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[3] If the ripple swells are of unequal magnitude, one must use the ratio of the length of the ripple swell to its height.

[4] The limitations on the scope of this article unfortunately preclude a presentation of these interesting and variegated data.

Table 4

Classification of bedding by dimensions

Intervals of thickness	Definitions of internal stratification of rock (layering) by thickness of series	Definition of layers by their thickness	Definition of bedding in the series stratification) by the thickness of the beds		Terms used by various authors, mainly for horizontal bedding (after Ye. P. Bruns, V.A. Aprodov, N.B. Vassoyevich, L.B. Rukhin and the Glossary of Geology; given for comparison
			Usual definition	When the bedding planes are distinct, may be called:	
More than 1 meter	Very thick (coarse)	Very thick (rare)	Very thick (coarse)*	Thick block-like bedding	Block-like, massive, massive bedding, thick beds
1 m 10 cm	Thick*	Thick	Thick*	Block-like*	Block-like, massive, coarse-bedded, large beds, medium-bedded, medium beds
10 cm 1 cm	Thin*	Very large 5 cm Large*	Thin*	Plate-like*	Thick- large- and medium-bedded Thick- medium- and thin-bedded, thin beds
1 cm 0.5 cm		2 cm Medium (usual)*	Fine	Sheet-like	Thin-bedded, laminar bedding, quasi-laminar
1 mm		5 mm Thin*	Very fine	Laminar	
Less than 1 millimeter	Does not occur	Very thin* (sometimes called microlayers)	Extremely fine (microstratification) — rare	Fine laminar (microstratification)	Laminar bedding, microbedding, very thin bedding

*Most common types in nature.

Table 5

1. Definitions of types, subtypes, kinds and varieties

Types (simple)	Cross		Cross-rippled	Rippled	Gently rippled	Horizontal
Subtypes	By magnitude (thickness of series of layers (see Table 4)* Very thick (coarse) — more than 1 m Thick — 1 m - 10 cm Thin — 10 cm - 1 cm Very thin — less than 1 cm					If there are no series, subtypes cannot be distinguished in horizontal bedding
Kinds	According to relationship of contact surfaces between series...layers					
	Parallel Non-parallel, intersecting at small angles (wedge-shaped) Non-parallel, intersecting at small angles (criss-crossed)	Sub-kinds, according to form of contact surfaces between series a) straight b) bent	Non-parallel, offset Non-parallel, (criss-crossed)	Parallel Non-parallel, intersecting at small angles (offset) Non-parallel, intersecting at large angles (criss-crossed)	Parallel Non-parallel offset	According to uniformity of distribution in the bed (of series, packs, layers) Uniform (evenly distributed) Non-uniform but changing regularly Non-uniform (unevenly scattered)
Varieties	a) According to shape of layers		of contact surfaces between series and layers		a) According to uniformity of distribution of layers	a) According to structure of bed
	Straight Concave (underlying) S-shaped (concavo-convex) Convex		Concave Concavo-convex Convex	Concave Concavo-convex Convex	Uniform, (evenly distributed) Non-unif., changing regularly Non-unif., (unevenly scat.)	Homogeneous Cyclic (rhythmically repeated packs of layers) Series
	b) According to directions of layers in adjacent series			b) According to symmetry of ripples	b) According to continuity of layers	b) According to regularity of layers:
	In same direction In different directions: alternating irregularly		In same direction In different directions irregularly	Symmetrical Asymmetrical	Continuous Discontinuous	Regular Irregular

2. Criteria by which bedding is determined

3. Characteristics (form and structure)

For cross, cross-rippled and rippled bedding	For gently rippled and horizontal bedding
a. Layers, Table 2: point 2. Interrelationship of layers in series (parallel or underlying) " 3. Texture of layers " 4. Inclusions in layers " 5. Distribution of layers in series " 6. Thickness of layers " 7. Angle of inclination (steepness and change along lateral extent of series)	Texture of layers Inclusions in layers Thickness of layers
b. Contact surfaces between layers: 1. Distinctness (sharp, clear, indistinct, gradual transition, hidden) 2. Continuity (continuous, discontinuous, disappearing, highly discontinuous) 3. Regularity (regular, irregular) 4. Manifestation and emphasis (clay coating, micaceous deposits, plant detritus, etc.)	
c. Contact surfaces (seams) between series, Table 3: point 1. Form point 2. Inclination	
1. Distinctness 2. Continuity 3. Regularity 4. Manifestation and emphasis	Same as for contact surfaces between layers
d. Series of layers, Table 3: point 3. Change in material of series point 4. Inclusions and their mode of occurrence	
e. Distribution of series in bed, Table 3: point 5a. Change in dimensions of series point 5b. Change in composition of series point 5c. Change in inclination of layers from series to series	Change in composition of series, packs or layers Change in dimensions of series, packs or layers

NOTES:
1. After definitions of layers according to thickness, fluctuations in thickness are given in brackets.
2. Points c and d are indicated for horizontal bedding, if there are series or packs of series.
3. Point e for horizontal bedding: if there are no series or packs, distribution of layers in the bed is given.
4. For compound types of bedding, the characteristic features of the simple types composing them are given.

series of layers and by oblique layers inclined at an angle to the base of the series. This bedding is formed by weak currents and is mainly the result of current ripples. Both genetically and in morphological features, it is intermediate between cross and rippled bedding. Gently rippled bedding is the intermediate type between typical rippled bedding and horizontal bedding. Bedding of this type is produced by very weak waves agitating the bottom sediments. It is characterized by a high ripple index — the ripples decrease very gently — and its other characteristics approach those of rippled bedding on the one hand, and horizontal bedding on the other.

Subtypes within each type are distinguished on the basis of the series thickness: very thick, thick, thin and very thin (see Table 4). The most commonly encountered are thick and thin. In the case of horizontal layering, in which the layers frequently do not form series, there can be no subdivision of subtypes; one can only determine the bedding by the thickness of the beds and the size of the layers themselves.

A further subdivision of bedding (layering) is made within each type, into kinds and varieties (see Table 6). Here it is very important to decide correctly which indices are those of kind, which are those of variety and which can be used only for description.

All these criteria have been chosen with a view to their genetic significance, so as to facilitate the ultimate transition from this morphological classification to the construction of a genetic one. Omitting all the arguments in favor of this or that particular index, let us merely describe them (see Table 5).

The common and determining index in the case of all four types — cross, cross-rippled, rippled and gently rippled bedding — is the relationship of the contact surfaces: between series for the first three types, and between layers for the gently rippled type of bedding.

The following kinds of bedding are distinguished within each type: parallel, non-parallel intersecting at small angles (offset), and non-parallel intersecting at large angles (criss-crossed). The intermediate types do not have all kinds: cross-rippled bedding lacks the parallel kind, and gently rippled bedding the criss-crossed.

The kinds of non-parallel (offset and criss-crossed) cross bedding are divided into two subkinds by the shape of the contact surfaces between the series — straight or bent: straight when the series contacts appear as straight lines in the vertical section, and bent when they form irregular curved lines, the curvature being manifested to a greater or lesser degree.[5]

In the case of horizontal bedding, the kinds within a type are distinguished by a completely different criterion — by the regularity of the distribution of layers in the bed, as well as of packs and series of layers. These kinds include: uniform (evenly distributed), non-uniform with regular change in distribution, and non-uniform (unevenly scattered). The uniformity or lack of uniformity is determined by the change in thickness of the layers, and the evenness or unevenness by the change in their composition.

The varieties are distinguished according to two criteria. The first such is the shape of the layers, which is common to all three types — cross bedding, cross-rippled and rippled bedding. There are four varieties: straight, concave, concavo-convex and convex, of which the first (straight) is encountered in cross bedding only. The first criterion for distinguishing varieties of gently rippled bedding — the uniformity of distribution of the layers in the bed — approaches horizontal bedding, of which it is a kind. The first criterion for distinguishing varieties of horizontal bedding is the texture of the bed: simple (composed of layers), cyclical (composed of packs of layers) or series (composed of series of layers). The second criterion for distinguishing varieties, which applies only to two types — cross and cross-rippled bedding — is the direction of inclination of the layers in adjoining series (in the same direction or in different directions, alternating by series or without any order). Rippled bedding is divided according to the symmetrical or asymmetrical shape of the layers; gently rippled bedding by the continuity of the layers into dontinuous and discontinuous; and horizontal bedding, according to the regularity of the layers, into regular and irregular varieties.

Thus it is clear that the more detailed the subdivisions, the less widely can the characteristic indices for the different types of bedding be applied. In the case of intermediate types of bedding, the indices or criteria are also intermediate.

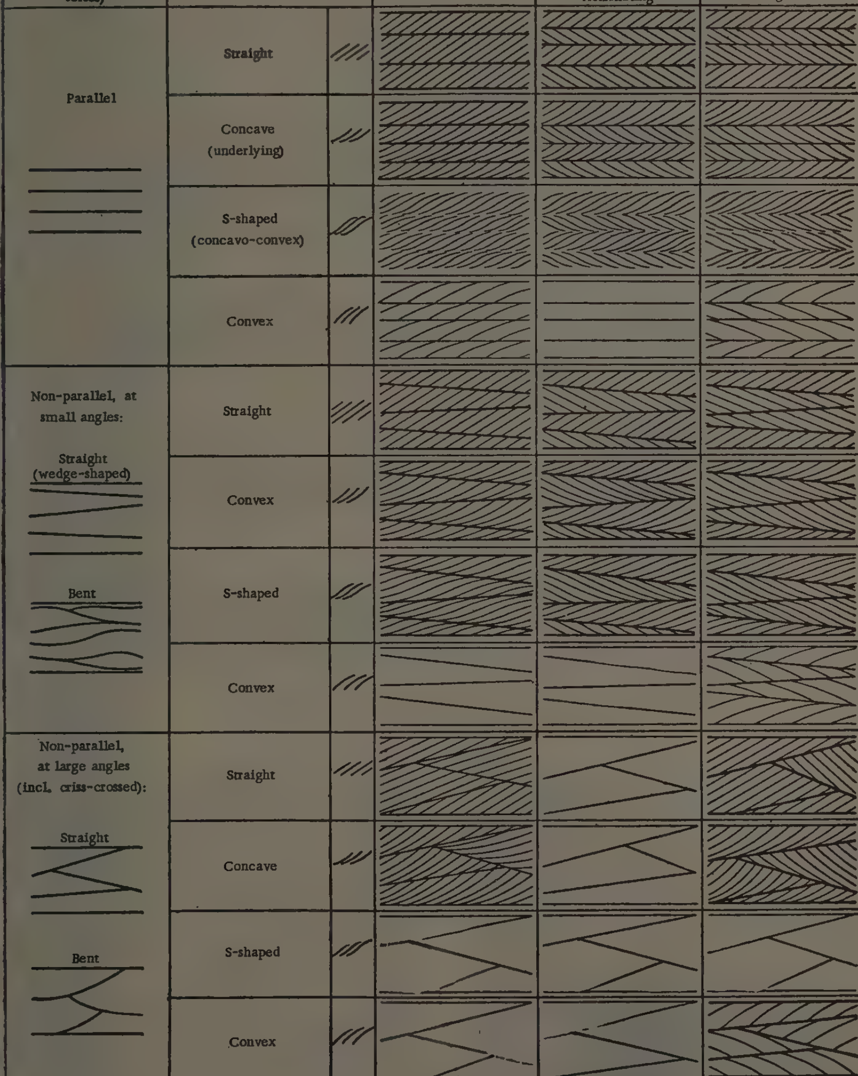
After determining the type, subtype, kind and variety of the bedding (layering), one must indicate the criterion by which they have been determined: sorthing, change in granulometric composition, segregations of ore minerals, appearance of inclusions, the presence of plant detritus or argillaceous coating on the bedding or layering planes, the sharpness of the contact surfaces (seams) between the layers, and others. Sometimes the bedding

[5] **Table 6 shows diagrams of the subkinds for straight cross bedding only.**

Table 6

Classification of cross bedding (subtypes are distinguished by magnitude of series)

Types (by interrelationship between series) and subtypes (by shape of contact surface between series)	Varieties: a) By shape of layers		Varieties: b) By inclination of layers in adjacent series: In same direction	In different directions: Alternating	In different directions: Irregular
Parallel	Straight				
	Concave (underlying)				
	S-shaped (concavo-convex)				
	Convex				
Non-parallel, at small angles: Straight (wedge-shaped)	Straight				
	Convex				
Bent	S-shaped				
	Convex				
Non-parallel, at large angles (incl. criss-crossed): Straight	Straight				
	Concave				
Bent	S-shaped				
	Convex				



r layering is emphasized by secondary erruginous stain along the contact surfaces etween layers or surfaces.

This point is significant for all types of bedding, but in the case of horizontal bedding it frequently assumes a leading role. This is associated with the fact that the morphology of horizontal bedding is very monotonous, and many indices in it are indistinct or else totally

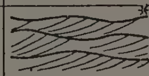
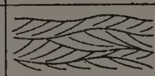
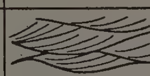
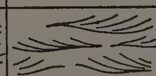
lacking. For this reason the texture of the layers and beds becomes the primary criterion in bedding of the horizontal type. One example is the widely known rhythmic or cyclical sorting, described as "graded bedding", associated with the formation of turbidity currents of high density under special conditions [18, 19]. In form this is related to horizontal bedding, but its particular character is determined by the internal texture of the units of stratification.

A further characterization of the bedding is made by describing (Tables 5, 3) the contact surfaces between layers and series of layers and the series, and their distribution in the bed. In this regard cross bedding, cross-rippled and rippled bedding usually have far more detailed and minute features than horizontal bedding, which lacks indices associated with the form and inclination of the layers and with the contact surfaces between series of layers.

Moreover if the layers in horizontal bedding do not form packs or series, this characteristic naturally cannot be given, and in category "e" in Table 5, instead of the distribution of series in the bed, one must indicate the nature of the change in the layers throughout the section of the bed.

Table 6-a

Classification of cross-rippled bedding
(Subtypes distinguished by magnitude of series of layers)

Types, according to relationship of series	Varieties		
	By shape of contact surfaces between series (only asymmetrical)	By direction of inclination of layers	
		In same direction	In different directions, irregularly
Non parallel at small angles (offset)	Concave	—	—
	Concavo-convex		
	Convex	—	—
Non-parallel at large angles (criss-crossed)	Concave		
	Concavo-convex	—	—
	Convex		

* Sometimes more appropriately called "current-ripple bedding."

All the possible varieties of bedding — in cross bedding, cross-rippled, rippled, gently rippled and horizontal bedding — have been presented in order in Tables 6, 6-a, 7, 7-a and 8. In these tables the closely spaced hatching indicates the varieties that are typical and frequently encountered; the widely spaced hatching shows the uncharacteristic varieties, which are either mentioned in the literature or which have not been described but are theoretically possible. The blank, unhatched boxes indicate varieties that have not been observed and whose occurrence is scarcely possible (inasmuch as the mechanism of their formation would require combinations of conditions that are not encountered together in nature). The present writer believes that any simple type of bedding that might be encountered must necessarily fall into one of the boxes provided in these five classification tables.

Besides the five simple types of bedding

Table 7

Classification of rippled bedding (subtypes distinguished by magnitude of series of layers

Types, according to relationship between series	Varieties		
	By shape of contact between series and layers	By symmetry of ripples	
		Symmetrical	Asymmetrical
Parallel	Concave		
	Concavo-convex		
	Convex		
Non-parallel, intersecting at small angles (offset)	Concave	*	
	Concavo-convex	*	
	Convex		
Non-parallel, intersecting at large angles (criss-crossed)	Concave	**	**
	Concavo-convex	***	***
	Convex		

* Sometimes layers within one series may be parallel.
** Called "trough-shaped".
*** May sometimes produce lens-shaped layering.

Table 7-a

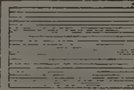
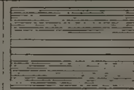
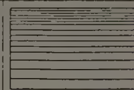
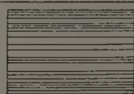
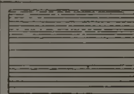
Classification of gently rippled bedding (subtypes usually not distinguished)

Types, according to relationship of layers	Varieties		
	By uniformity of distribution of layers	By continuity of layers	
		Continuous	Discontinuous
Parallel	Uniform (evenly distributed)		
	Non-uniform but changing regularly		
	Non-uniform (unevenly distributed)		
Non-parallel (offset)	Uniform (evenly distributed)	*	
	Non-uniform, but changing regularly	*	
	Non-uniform (unevenly scattered)	*	

* May produce lens-shaped bedding.

Table 8

Classification of horizontal bedding. Subtypes distinguished by magnitude of series (if there are no series, horizontal bedding lacks subtypes)

Types (by uniformity of distribution in bed)	Varieties (by texture of bed)		
	Simple	Cyclical	Series
Uniform (evenly distributed)			
Non-uniform, but changing regularly (incl. "pendulum-wise")			
Non-uniform (unevenly scattered)			

* Including banded varieties.

described above, there are also compound types which may be either: 1) a constant, stable combination of two (rarely more) simple types or kinds, for example diagonal bedding (an alternation of horizontal and cross-bedded series, as in Fig. 1, stratum D) and rippled bedding in multiple stages (an alternation of gently rippled series with groups of rippled series, Fig. 1, stratum C); 2) some particular combination of layers of one rock with series of layers of another rock (for example, lenticular-rippled); 3) a bed whose structure is composed of series, and that of the latter of packs of layers. The occurrence of compound types, like that of simple ones, is determined by the facies conditions of sedimentation and deposition, so that their number is limited and they cannot be manifested as any combination of simple types; as would appear from J. Morawski's paper [23], for example.

The manifestation of the bedding may be distinct, indistinct or not in evidence at all. In the last case, the bedding (or layering) may appear in a smooth, plate-like cleavage parallel to the stratification, in the disposition of the particles composing the rock, in the distribution of various inclusions, or, finally, the layering may be so fine that it can be distinguished only under the microscope (microstratification).

In defining the morphological types of bedding discernible in the plane of a single section, it must not be forgotten that in a number of cases a different section of the same rock may show another morphological type of bedding texture. Thus one must always attempt to visualize the bedding in three dimensions, or two sections, preferably mutually perpendicular.

These definitions of the indices of bedding may serve as the basis for conclusions regarding the mechanism and conditions of formation of the bedding and, beyond this, of the facies conditions. Thus from the bedding indices one approaches the genesis of the rock. The morphological classification that has been proposed in this article will provide the foundation for a genetic classification of bedding textures.

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DIAGENETIC DISLOCATIONS OF THE BEDDING AND LAYERING IN THE ORE-BEARING ROCKS OF THE DZHEZKAZGANSKAYA SUITE[1]

by

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This article describes the varieties of bedding textures that have been formed in the ores of Dzhezkazgan during the sedimentation and diagenesis of the primary ore-bearing deposit. The diagenetic dislocations of the bedding and layering in the ores, the types of interformational sedimentary breccias and the nature of the mineralization in them are examined.

New facts are advanced to explain the conditions of the formation and genesis of the Dzhezkazgan ores; the author believes that these leave no room to doubt the primary sedimentary nature of the ore mineralization of this deposit.

* * * * *

I. GENERAL REMARKS

In his study of the rocks of the Dzhezkazgan suite, the present writer has encountered a number of new and interesting lithologic peculiarities which are of great importance in deciphering the conditions governing the formation and genesis of the Dzhezkazgan ores. Specimens of the ores being studied were collected from the underground workings of the main ore districts of Dzhezkazgan, both by the author personally and by the mining geologists of Dzhezkazgan (L. F. Narkelyun, L. I. Ivankov and G. D. Mladentsev).

It is known that the sediments that make up the Dzhezkazgan ore-bearing suite were deposited in a shallow-water marine epicontinental basin, in which there was a cyclical tectonic oscillatory movement against the background of a general uplift of the region. The shallow-water nature of the Dzhezkazgan deposits and the cyclical oscillatory movements during the time of their formation are evidenced by the clearly cyclical structure of the suite and by the widespread distribution in it of traces of littoral surf zones, desiccation cracks, raindrop marks, cross bedding, tracks and traces of quadruped vertebrates, accumulations of plant detritus in individual beds and, finally, by the presence throughout almost the whole section of the suite of interformational breccias and intraformational conglomerates.

The last of these fix the times of the short-lived periods of erosion and redeposition of the rocks of the Dzhezkazgan suite. The intraformational and conglomerates usually occur at the base of the sedimentation cycles, which are clearly marked in the Dzhezkazgan rocks; each is composed of two series of strata of different colored rock: gray sandstones and red siltstones and argillites, grading into intermediate shades between them.

The gray series of layers, beginning with the intraformational conglomerates at the base, correspond to the transgressive part of the sedimentation cycle, with which the accumulation of ores in Dzhezkazgan is also associated; the red-colored layers correspond to the regressive portion of the cycle, and as a rule these beds in Dzhezkazgan do not contain any ore mineralization. The only ore-bearing strata are the gray sandstones and the beds intermediate between gray and red, composed of finer-grained varieties of rock (siltstones and argillites, whose colors range through various shades of grayish red and reddish gray. The total thickness of the rocks deposited during a single sedimentation cycle varies from 20 to 70 meters. The eighteen such sedimentation cycles together form the complete section of the Dzhezkazgan suite, whose total thickness is about 650 meters. All the gray strata throughout the section of this suite are potentially ore-bearing.

The nine ore-bearing strata with mineralization of industrial importance that have been established in Dzhezkazgan are associated with gray-colored rocks and are separated

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[1] Diageneticheskiye narusheniya sloistosti i naplastovaniya v rudonosnyky porodakh Dzhezkazganskoy svity.

from each other by red-colored, oreless beds between them. The nature of the ore mineralization in the intraformational conglomerates, which contain the ore pebbles and sulfide-bearing grains in the cement that binds the pebbles together, has been discussed by the present author in a special article [2].

2. TYPES OF BEDDING STRUCTURES IN THE DIAGENETIC ORES OF DZHEZKAZGAN

Among the different types within the ore-bearing rocks of Dzhezkazgan, one aspect of particular interest is the bedding textures of the primary sedimentary ores that have undergone diagenesis, but which have in essence not yet been subjected to later processes of epigenesis and metamorphism and have therefore not lost their primary features. The present writer has already given a partial description of the bedding textures in the Dzhezkazgan ores in an earlier article [3]. Here these structures will be considered in more detail.

It is important to note that both the bedding and the brecciated textures described below in the ores of Dzhezkazgan are usually encountered in the most fine-grained varieties of ore-bearing rock — the argillites and siltstones — whereas the greater part of the Dzhezkazgan ores, it is well known, is concentrated in the medium-grained sandstones. It is no less important to stress the fact that the most fine-grained and layered varieties of ore-bearing sediments in the section of each sedimentation cycle are located in the uppermost part of the gray-colored ore-bearing complex, which grades into the red oreless part of the section and terminates the first half of the cycle in which the ore material is accumulated in the sediments.

The varieties of bedding textures in Dzhezkazgan include: thin parallel beds grading into lenticular layers, with straight and parallel bedding planes (Fig. 1); and cross-rippled and cross-bedded lenticular varieties grading into purely lenticular beds, the latter characterized by the lack of parallel bedding planes and by the presence of wavy bedding and cross bedding (Fig. 2, 3).

It is noteworthy that the textures enumerated above contain segregations of copper sulfides (primarily chalcosite and bornite, more rarely chalcopyrite, galena and others) which, like the other components of the rock, form thin interbeds, lenses aligned with the bedding planes, and nodules or cross and wavy beds. The ore minerals among the elements in the texture of the ore-bearing rocks faithfully repeat all the details of their structure. With their darker color, the sulfides still more sharply underline the structural features of the rocks that contain the ores. Thus the ore minerals, together with the terrigenous particles that cement them, are themselves an integral part of the sometimes very complex textures of the rocks. These textures developed in the primary clay sediments that undoubtedly already contained the ore material, which thus was involved in all the processes of sedimentation and diagenesis.

The sulfides typically do not introduce any thermal alterations into the rock; they merely produce a darker coloring of the sulfide-enriched parts, which are clearly distinguishable against the greenish-gray and less often reddish color of the rock.

When the mineralization occurs in the non-bedded, fine-grained rocks — the massive,

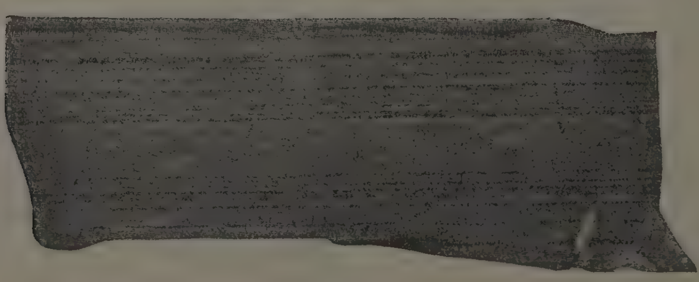


FIGURE 1. Thin-bedded texture in the ore: black lines are copper sulfides (bornite, chalcosite) located along the elements of the thin and parallel layering of the siltstone, forming thin interlayers. Dzhezkazgan, Pokro, Horizon 230, Deposit 7. Photograph of specimen is 2/3 natural size.

ructureless argillites and siltstones — the e minerals take the form of a very fine, spersed sulfide bloom more of less evenly stributed through the mass of the rock witht forming any layered segregations. This oom cannot be distinguished from the rock

FIGURE 2. Banded, cross bedded, lenticular texture in the ore.

Black portions are copper sulfides (bornite, chalcosite) forming wedge-shaped interlayers, and lenses that repeat and determine the primary cross bedding of the enclosing rock (siltstone). Dzhezkazgan, Pokro, Horizon 230, Deposit 7. Photograph of polished surface is 3/4 natural size.

the naked eye, and can be discerned only polished surfaces under reflected light with binocular microscope. In this case the ineralization shows no change within the iclosing rock, which cannot be visually disnguished from the oreless rock.

Another particularly interesting aspect of e Dzhezkazgan deposits is the sulfide minalization in the reddish, usually finely disrsed rocks (argillites, siltstones and clay shales) that form the transition to the oreless red-colored beds. Here the thin interlayers of ore, the ore lenses and shapeless segregations of sulfides are, as a rule, surrounded by an aureole in which the color has been leached out, forming thin greenish-gray borders around the sulfide segregations. In the non-bedded rocks the leached aureoles around the segregations of sulfides have irregular shapes corresponding to the shapes of the ore-bearing parts, so that the rocks themselves have a motley color resulting from the gray-green spots standing out against their generally red background.

The origin of these color-leached aureoles about the sulfide segregations in the red rocks is closely tied to the physicochemical conditions under which the sulfides were precipitated out, and cannot be considered to bear any relation to any kind of hydrothermal alteration around the ore. It is known that copper sulfides are formed in a reducing medium, so that the ferric oxide compounds that produce the red color of the enclosing rock would naturally have been reduced under these conditions to ferrous oxide forms, accompanied by a change in the color about the sulfide segregations from the red of the surrounding rock to grayish-green. Hence the formation of the sulfides was simultaneously accompanied by the reduction of $Fe^{\cdot\cdot\cdot}$ to $Fe^{\cdot\cdot}$

The connection between the primary ore mineralization in Dzhezkazgan and the changing oxidation-reduction conditions, as reflected in the color of the rock, has been analyzed in greater detail by N.S. Manuylova [1] and fully confirmed by newly discovered facts. Moreover the recent discovery (by L.F. Narkelyun) in Dzhezkazgan of a vertical and horizontal zonality of the ore minerals in the ore deposits corresponds strictly to the oxidation-reduction potential. A consideration of these problems, however, is not within the scope of this article.

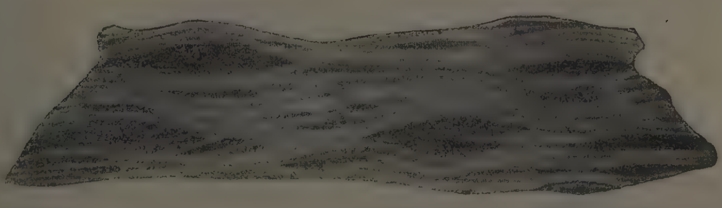


FIGURE 3. Lenticular texture in the ore.

Black portions are copper sulfides (chalcosite, bornite) in the gray siltstone, forming lenses (nodules) and interlayers that wedge out, following the elements of the cross bedding and forming a part of it. Dzhezkazgan, Pokro, Horizon 230, Deposit 7. Photograph of lump of ore is 3/4 natural size.

Some note must also be made of the extraordinarily variegated physicochemical conditions, to which N.M. Strakhov [7] has drawn special attention, even within a single bed of comparatively small thickness, whose material and granulometric composition is more or less uniform. The most characteristic indication of the physicochemical medium, the Eh, as expressed in the color of the rock, fluctuates greatly even between adjacent small areas; the low values of the oxidation-reduction potential are frequently limited to very small portions of the rock colored grayish green. These narrowly localized areas, which are sometimes measurable in fractions of a millimeter, are usually the places in which the sulfides and the organic matter are accumulated; within them one may often see fragments of plant remains, sometimes with tiny globular pyrite segregations that are doubtless of biochemical origin.

In the layered varieties of the sulfide ores the black coloring of the ore interlayers is due not only to the accumulation of sulfides in them, but also to the concentration of finely disseminated organic detritus.

Whenever the mineralization takes the form of a disseminated bloom or of very thin and discontinuous interlayerings, leaching out of the color from the rock is not observed or is very slight and scarcely noticeable.

All these features of the ore mineralization testify to the very close and precise control of sulfide formation by the oxidation-reduction potential. The extremely close relationship between the ore deposition and the value of the Eh in the medium of sedimentation is manifested on a large scale in Dzhezkazgan; this determines the exclusive association between the ore-bearing horizons in the section of the Dzhezkazgan suite and the complexes of gray-colored beds, and the absence of ore mineralization in the red-colored rocks that alternate with them. This relationship is also manifested on smaller scales, down to microscopic.

This is one of the most remarkable and characteristic features of Dzhezkazgan and is, generally speaking, repeated clearly in all of the sedimentary deposits of cupriferous sandstones both in the U.S.S.R. and in other countries (in the Donets Basin, the Western Urals region, Tataria, the Mangyshlak, Mansfield, Corocoro in Bolivia, the Redbeds of the U.S.A., etc.). A similar picture is observed in all the deposits of cupriferous sandstones of the Atbasar-Tersakkan region in the western part of Central Kazakhstan, which have come to be recognized as classic sedimentary formations, and also in similar deposits of Central Asia (the Naukatskoye, Gaurdakskoye, the Kirgiz Range, etc.).

3. DIAGENETIC DISLOCATIONS OF THE BEDDING AND STRATIFICATION IN THE ORE-BEARING ROCKS OF DZHEZKAZGAN

Without dwelling in detail on the problems touched upon above, which have recently been considered thoroughly by N.M. Strakhov [7], let us examine the dislocation of the bedding and stratification in the ore-bearing rocks of Dzhezkazgan that has come about during their diagenesis and in the course of the formation of the Dzhezkazgan ore-producing suite. In studying this phenomenon, the present author has traced its development from the initial stages to the formation of typical interformational rupture and slip breccias.

In the thin-bedded ore-bearing argillites in Figures 4 and 5 one may clearly see the beginnings of dislocations of the type of steeply dipping intersection microfaults, displacing a series of thin ore interlayers and almost completely dying out within the limits of the ore lump. There is also a disturbance in the parallel disposition of the layers, which have undergone very gentle bending and torsion without disrupting their continuity. In places the series of interlayers have been deformed, resulting in a decrease or increase in the normal space between them (Fig. 6).

Besides the steeply dipping microfaults that shear through the layers, there are dislocations close to the layering or oriented in the bedding planes with deviations of small acute angles (Fig. 5); sometimes these even combine with dislocations of the first type and grade into each other.

The further development of such dislocations leads to greater displacements of the individual small blocks of the rock, which slide past each other and even may lose their initial orientation in space relative both to each other and to the general direction of the bedding.

Figures 7 and 8 clearly illustrate dislocations of these types, which are recorded in two photographs of the same specimen, taken of two different polished surfaces at right angles to each other.

Figure 7 shows that a block with thin-zoned sulfide mineralization has been displaced along the bedding plane in the rock surrounding the ore, in the direction indicated by the arrows, and has come to occupy an "unconformable" position relative to the block of non-bedded argillites below it. The direction of the movement is testified by the dislocation of the ore layers in the displaced block (downward from the left). In the lower portion of the specimen a part of another displaced block of thin-layered ore is visible, and at the very

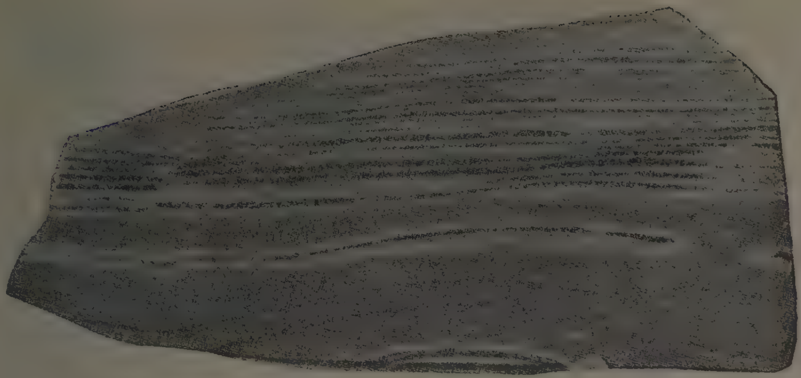


FIGURE 4. Thin-bedded texture in ore.

Black areas are copper sulfides (bornite, chalcosite) forming thin curving interlayers in the reddish argillite; a microfault has broken and offset the interlayers of ore. Dzhezkazgan, Pokro, Southwest, Mine 45. Photograph of ore lump is 3/4 natural size.

ottom (the white area) there is a calcite-arite vein parallel to the bedding; this vein as a transverse columnar structure. It is uite typical that the sulfide segregations in ıese veins, like the vein minerals themselves calcite and barite), have an acicular strucıre perpendicular to the vein and the bedding lanes, so that the sulfides are associated rimarily with the parts of the veins that cut ırough the ore layers of the blocks of banded res. The argillites themselves contain a ulfide bloom in the form of finely scattered isseminations. It should be noted that in the veins described above one encounters only such sulfides as are found in the argillites enclosing the veins and in the block of banded ore.

The formation of banded veins is connected with later processes occurring during the stage of epigenesis or even the initial stages of dislocational metamorphism that are manifested in the secondarily indurated rock.

Figure 8 shows another side of the same specimen; this gives an idea of the displaced

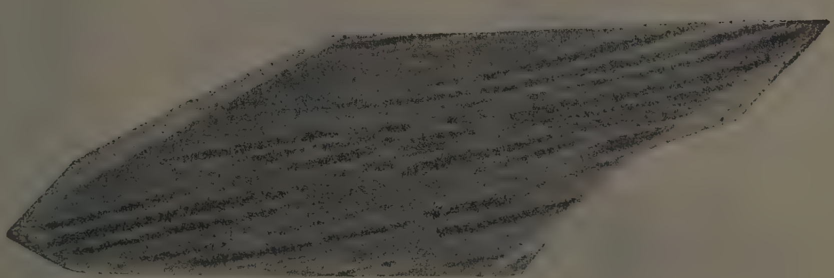


FIGURE 5. Thin-bedded texture in the ore.

Black portions are copper sulfides (chalcosite, bornite) forming thin interlayers in the reddish argillite. A perpendicular microfault has broken the series of ore interlayers; their displacement may also be observed in the other plane, close to the surface. Dzhezkazgan, Pokro, Southwest, Mine 45. Photograph of ore lump magnified 1.5 times.

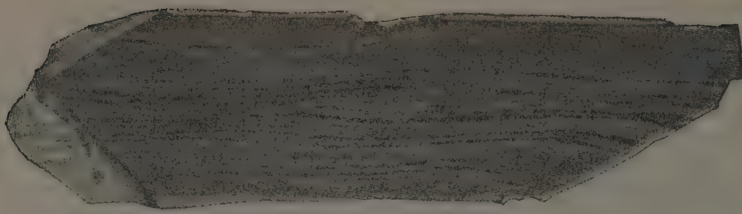


FIGURE 6. Thin-bedded texture in the ore.

Black lines are copper sulfides (bornite, chalcosite) forming thin, deformed interlayers in the reddish argillite. Dzhezkazgan, Pokro, Southwest, Mine 45. Photograph of ore lump is 3/4 natural size.

Figure 7

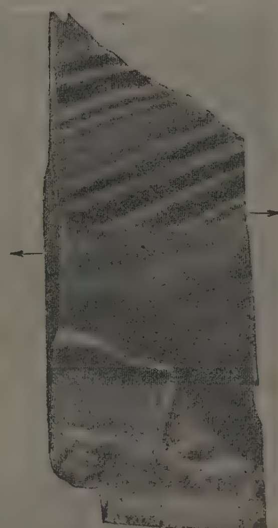


Figure 8

FIGURE 7. Slip displacement of a block of layered ore in reddish argillite, resulting in an "unconformable" occurrence.

The dislocation of the ore layers may be seen in the lower left corner of the block. In the lower part of the lump are layered (in relation to the argillites) calcitic-baritic veinlets of the "Alpine" type, cutting through another displaced block of layered ore. The argillite contains a finely dispersed sulfide bloom (bornite, chalcosite) in the form of tiny black dots. Dzhezkazgan, Mine 45. Photograph of ore lump is 3/4 natural size.

FIGURE 8. The same ore lump as in Figure 7, photographed in another plane.

In the lower part of the displaced block of thin-bedded ore one may see the traces of the ore interlayers (black). The arrows indicate the direction of the displacement. Magnification 1.25 times.

e block in the plane perpendicular to that the preceding illustration. It will be seen at the displacement has taken place in the rection shown by the arrows, and has been companied by dislocation of the ore layers, which only fragments have been preserved ar the plane of displacement, and that the lor has been leached out of the red argil-tes over which the ore block has moved. he ore layers of the displaced block (black) Figure 8 have a greater thickness than ose in Figure 7; this is due to the fact that e polished surface cuts these layers at an lique angle to the plane of layering, where-s in the first polished section the surface e surface cuts the ore layers normal to the rection of the layering.

Thus the pictured specimen clearly illus-ates, on the one hand, the phenomena elated to the period of diagenesis, which are evealed in the dislocations of the layering ad the slippage of separate parts of the emi-indurated sediment, and, on the other and, the subsequent processes involved in e formation of veins of the "Alpine" type. uch veins are due to later tectonic move-ents in the already fully lithified ore-bearing ock, during the time of folding, which en-ompassed the entire thickness of the deposits the Dzhezkazgan suite. The vein material as been taken entirely from the surrounding ocks and is thus the product of redeposition f the minerals contained in it.

A feature of special interest is the nature f the ore mineralization in the specimen just escribed, both within the displaced blocks ith their banded textures and in the unstrati-ied argillites against which these blocks have een moved. In the first case the copper ulfides are confined to the dark bands and to considerable degree determine their color, nd are lacking in the intervening lighter-olored bands. The chief sulfide here is ornite, which forms a dense segregation ithin the black layers that merges into almost olid portions; white chalcosite is observed in ery small amounts in the form of isolated egregations. The black color of the ore ands is typically produced not only by the ccumulation of sulfides, mainly bornite, but lso by the presence of finely disseminated rganic detritus, whose nature has not yet een sufficiently well determined. In the nstratified reddish argillites the ore minerali-ation consists of a disseminated fine bloom f copper sulfides more or less evenly distrib-ted through the mass of the rock.

The size of the separate and always isolated iny ore segregations does not exceed tenths, nd more often hundredths and even thou-sandths, of a millimeter. These segregations nay be seen only under the microscope, in a olished surface with reflected light. Such ore mineralization is often connected with the lithologic peculiarities of the surrounding rocks, which are unstratified massive finely dispersed argillaceous formations (argillites and pelitic siltstones) that expand and crumble readily in water; the latter circumstance has greatly hindered the preparation of thin sections.

The sulfide segregations are represented by two minerals present in different quantities — bornite and chalcopyrite; both minerals form very tiny nodules, within which they are seen to be closely intergrown. More rarely the bornite and chalcopyrite form segregations by themselves.

Thus the ore mineralization within the displaced layered blocks differs essentially from that in the unstratified argillites, both in texture and structural features and in mineral composition. The common mineral in both is bornite; chalcosite is observed in the banded ore and is absent in the argillites, whereas chalcopyrite is the typical mineral in the unstratified argillites but has not been found in the banded ores. These are the two types of ore mineralization that have appeared in different parts of the same ore-bearing bed whose slip dislocation has brought them into contact within the same lump of ore.

4. TYPES OF SEDIMENTARY INTERFORMATIONAL BRECCIAS AND THE NATURE OF THE ORE MINERALIZATION IN THEM

In addition to the diagenetic dislocations of the bedding on relatively small scales that have been described above, in the ore-bearing rocks of the Dzhezkazgan suite one fairly often encounters larger dislocations in the bedding, which are also diagenetic, leading to the formation of typical interformational sedimentary crushing breccias, some idea of which may be gained from Figure 9. The more intensive dislocations divide the semi-indurated sediment into strata and create layers of ore-bearing beds; the latter are broken into separate plate-like fragments that are subsequently cemented by new sediment, which is usually coarser grained than that of the primary dislocated layers. The plate-shaped fragments of the ore-bearing sedimentary breccias in some cases are close to their original positions, occurring almost in situ; in other cases they are oriented at various different angles to the initial bedding. Even within a single ore lump it is possible to trace a transition from intensively brecciated portions to slightly dislocated or undisturbed layers that have undergone only slight disturbance. In the hanging wall and the foot wall, and also along their trends, such interformational breccias usually grade into

normally occurring, undisturbed layers. The thickness of the sedimentary breccias in the instances observed by the present writer is small and measurable in several centimeters, not exceeding 10 centimeters; the fragments are no more than several centimeters long and their thickness depends on the thickness of the broken primary layers, usually no more than several millimeters. The shape of the fragments is plate-like and angular, with rectilinear edges and angles.

The fragments in the intensively mineralized cement characteristically retain their sharp angles and rectilinear edges, undergoing no change. The intensity of the primary ore mineralization and its distribution in the fragments themselves also show no change resulting from the effect of the almost purely sulifde cement binding them together. There are absolutely no traces of metasomatism of the fragments. The same behavior typifies the surrounding rocks, which also retain their sharp angles and rectilinear edges unchanged; these edges and angles were formed by the same rupturing that produced the fragments in the breccias. There is a total absence of any alteration around the ore either in the fragments of the breccias or in the surrounding rocks, despite the very great intensity of the ore mineralization.

Thus the fragments that form the interformational breccia, like the enclosing rocks themselves, are completely inert in regard to the sulfides in the cement; in the fragments the initial layered character of the mineralization is preserved along with the primary intensity of the ore mineralization; the sulfides in the cementing substance, in turn, seem to have had no effect at all on the fragments and the surrounding rock. There are also siltstone "spin-tops" — reel-shaped formations containing ore layers that repeat all the complex features of the texture.

The formation of the interformational breccias is accompanied also by the migration of sulfides in the fractures within the enclosing rocks, parallel to and intersecting the bedding; the fissures are then filled by pure sulfides without any admixture of vein minerals. In this case the sulfides filling the fissures remain surprisingly passive in relation to the surrounding rock, having no effect upon it at all.

On the basis of the above-described features of the ore mineralization in the interformational breccias, it may be supposed that they were formed under conditions of physicochemical equilibrium; the ore components were in equilibrium with all the surrounding medium and therefore produced no changes in it. The absence even of any traces of thermal alteration in connection with the extremely rich ore

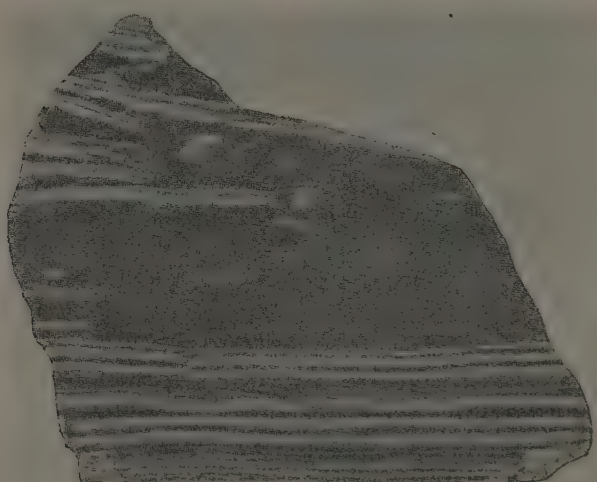


FIGURE 9. Interformational rupture breccia.

The fragments of thin-bedded ore-bearing argillites are cemented by a siltstone cement containing the richest ore mineralization (bornite, chalcosite) — the black areas. Dzhezkazgan, Pokro, Horizon 230, Deposit 7. Photograph of ore magnified 2 times.

mineralization in the breccias compels one to believe that the circumstances of the sulfide formation in them corresponded to the usual exogenic conditions of the zone of sedimentation in shallow-water basins.

In regard to their disposition in space, the sedimentary breccias in the Dzhezkazgan ore-bearing suite have developed in the rock in the vicinity of surf-zone traces, desiccation cracks, marks of raindrops, etç., which occupy a definite position in the sedimentation cycle. All this indicates without any doubt that the Dzhezkazgan interformational breccias were formed under the conditions of submarine gravity sliding in shallow waters during the periodic tectonic uplifts of the sea bottom. Under these conditions the sediment was temporarily raised above sea level and transformed into a semi-indurated mass which, however, readily fell to pieces during the subsequent sliding that was associated both with the oscillatory movements of the basin bottom and with the gravitational sliding of the sediment along the sloping bed of the basin. The sedimentary breccia of the type that has just been described may be classed as a ruptural breccia.

Besides the interformational breccias that appear in the clearly layered and finely disseminated rocks, the Dzhezkazgan suite frequently contains sedimentary breccias of another type, illustrated in Figures 10 and 11. This type, which may be called slide breccia, consists of extremely irregular fragments of greenish-gray argillites or solidified clay, with intricate, fanciful outlines, cemented by sandy or silty cement.

In this instance the dislocation has occurred in the interbeds of non-stratified, structureless argillaceous rock which in sliding were broken up into irregular fragments with complicated outlines. Despite their highly irregular configurations, the fragments nevertheless often have generally elongated shapes and within the bedded breccia are disposed roughly parallel to the overall bedding of the enclosing rocks and of the brecciated stratum itself. The individual fragments occupy the most varied positions relative to the bedding, and range in size from fractions of a millimeter to several centimeters; there is no indication of any sorting.

The thickness of these breccias is usually

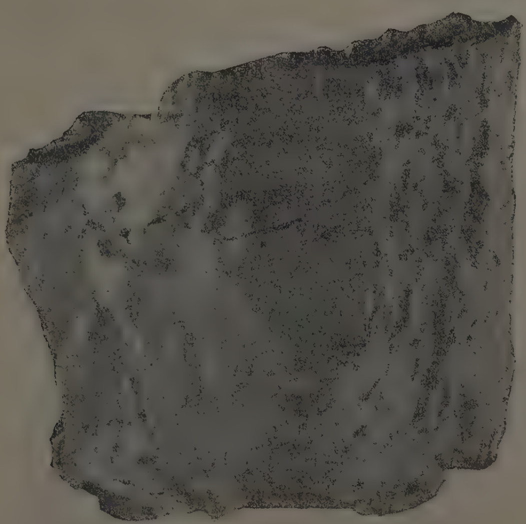


FIGURE 10. Interformational slip breccia.

The fragments of unbedded argillites with very finely dispersed sulfide bloom are cemented by a sandstone cement that contains the most intensive sulfide mineralization (bornite, chalcosite, galena); the white portion is a coarsely layered calcite vein with infrequent large segregations of the same sulfides. Dzhezkazgan, Pokro, Horizon 230, Deposit 7. Photograph of ore lump is 1/2 natural size.

much greater than that of the breccias formed by the rupturing of the thin-layered ore-bearing rocks, but according to the present writer's observations has not exceeded several decimeters, although it may also be considerably more. It should be noted that similar breccias are encountered in a number of cupriferous sandstone deposits of the Atabsar group.

There may perhaps be gradual transitions between the type of sedimentary breccia described immediately above and the intraformational conglomerates of Dzhezkazgan, although the latter occupy a different position in the sedimentation cycle, corresponding to the beginning of renewed sedimentation after a short interruption in the formation of sediments.

The breccia of this type is also ore-bearing and frequently contains rich mineralization, both in the fragments of argillites and clay rock and in the sandy cement of the breccia. In the fragments the ore mineralization as a rule takes the form of a fine disseminated bloom of copper sulfides (bornite, chalcosite, chalcopyrite, galena, etc.) that is distinguishable only in the polished surface of ore lumps under a binocular microscope.

The sulfide bloom in the fragments is distributed more or less evenly and does not form lenses and nodules of concentrated ores as in the interformational breccias, whose fragments consist of thin-layered rock. Figure 11 clearly shows the dense sulfide bloom concentrated in points in the argillite fragments.

The sandstone or siltstone cement of these breccias also frequently contains sulfide mineralization, which is sometimes very intensive and richer than that in the argillite fragments (Fig. 10); on the other hand, such mineralization may be totally lacking. In addition there are breccias in which the fragments with their dense sulfide bloom are cemented by sandstone cement that has little or no ore mineralization (Fig. 11). The sulfide mineralization may also differ in composition between the fragments and the cement of the breccia. All these facts testify that the mineralization in the fragments and in the cementing sandstone or siltstone material occurred at different times, though they took place in a single stratum of interformational breccia.

The earlier sulfide mineralization is that in the argillaceous fragments, since it was contained still earlier in the as yet undisturbed clay strata. The mineralization in the sandstone cement was later and syngenetic with the new sediment. The very same thing can be said regarding the succession of sulfide segregation in the earlier described breccias containing fragments of layered rocks.

This type of breccia also frequently bears traces of later, epigenetic processes, reflected

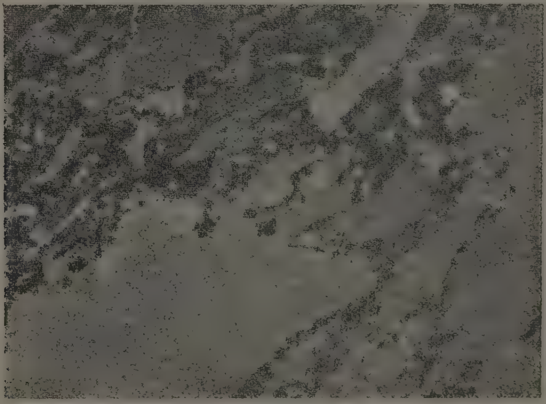


FIGURE 11. Interformational slip breccia.

The fragments of argillites with finely dispersed bloom of sulfides (black points are cemented by a sand cement containing rare segregations of sulfides. Dzhezkazgan, Pokro, Horizon 230, Deposit 7. Photograph of ore lump magnified 1.5 times.

such manifestations as veins of the "Alpine" type. These veins (Fig. 10) usually have a coarsely layered character, sometimes with fine intersecting branches. These mark the interformational movements involved in the subsequent processes of folding, which in Dzhezkazgan were accompanied by the formation of flexural folds and bedding dislocations. The thickness of such veins is small, often measurable in fractions of a centimeter to several centimeters, and rarely reaches 20 to 30 centimeters. The vein minerals are most frequently calcite and less often quartz, barite, gypsum and celestite. Sometimes the veins contain sulfides in infrequent segregations that are larger than those in the surrounding rocks; these latter often take the form of regular crystals combined in druses. The well-formed crystals of bornite, chalcosite, chalcopyrite, galena and others in the drusy cavities frequently reach several centimeters in size. Similar mineralized fissures have been observed in Dzhezkazgan not only among the interformational breccias, but also in any ore-bearing or oreless rocks. In the latter case they are also, as a rule, without ore.

A very characteristic feature is the fact that the veins contain only the sulfides encountered in the surrounding rocks. This peculiarity of the mineralized fissures of Dzhezkazgan is maintained with unvarying constancy throughout the whole ore field. This testifies that the vein ore minerals have been derived entirely from the surrounding rocks, so that their composition depends upon that of the latter.

Thus it follows from an examination of the mineralization in the ore-bearing interformational breccia of Dzhezkazgan that the minerals have been formed at different times and in three main stages, two of them diagenetic and one epigenetic. The earliest epigenetic stage of mineralization is marked by the fine bloom of sulfides in the layered and nonlayered fragments of the finely dispersed, primarily argillaceous rocks that compose the breccias; this ore mineralization must be considered as syngenetic with the enclosing rocks and to have been altered later during the diagenesis of the sediment. The mineralization in the cement of the breccia is later, and took place during the formation of the breccia itself, corresponding to one of the later stages of diagenesis, when the semi-indurated ore-bearing sediment was dislocated by slip movements and the resulting fragments cemented by new sediment containing sulfide minerals. The latest stage of mineralization, finally, is marked by the mineralized fissures in the veins of the "Alpine" type, in which the ore minerals are the products of redeposition of the sulfides contained earlier in the surrounding rocks and related to the first two, or diagenetic, stages.

It is also possible that the ore mineralization in the cement of the interformational breccia is partly the result of redistribution and redeposition of the ore material within the brecciated strata during epigenesis, and is thus simultaneous with the ore mineralization in the veins of the "Alpine" type.

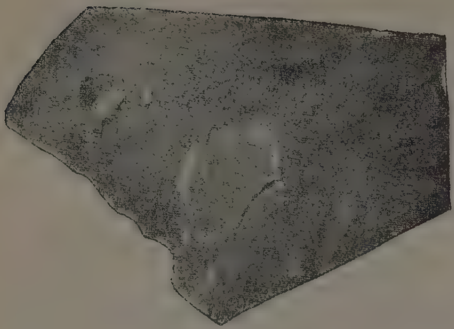
5. DIAGENETIC SULFIDE CONCRETIONS

Of particular interest are the recently discovered concretionary formations of different compositions and types in the ore-bearing rocks of the Dzhezkazgan suite; these contain both copper and iron sulfides or else consist entirely of such sulfides. The findings of sulfide concretions in the ores of Dzhezkazgan that have undergone recrystallization during epigenesis and the initial stages of metamorphism are, in general, quite rare; hence they are of all the more interest as clues to the actual nature of the ores in the deposit. Ore concretions in the deposits of the Dzhilandinskaya group, in the lower part of the Dzhezkazgan suite, are much more widespread. These concretions will be described below.

Concretions found in the workings of the Pokro mine, from the Pokro-8 deposit, are shown in Figure 12; their composition is sulfide-calcareous, and the enclosing rock is a greenish-gray argillite. The greatest size of the concretions is 15 to 20 millimeters in diameter and their shapes are generally round, oval or more complex and bounded by irregularly curved surfaces with concavities and convexities.

The bodies of the concretions consist of carbonate material containing a finely disseminated chalcopyrite bloom in individual magnitudes of tenths or hundredths of a millimeter. The larger segregations of chalcopyrite are concentrated in the peripheral zones of the concretions, where the combine to form a discontinuous outer shell of sulfides with an average thickness of some 0.5 millimeter. The thin layering of the surrounding argillaceous rock clearly reveals the concretions (Fig. 12), indicating that they originated in the course of diagenesis within the still unconsolidated sediment.

One interesting fact is that some parts of the outer rim of the concretions are separated from the surrounding rock by fine veinlets of acicular calcite. These evidently originated in the desiccation of the concretions and their drawing away from the enclosing rock; the gaps left by this separation were filled with parallel fibers of calcite, the fibers of which are oriented normal to the walls of the



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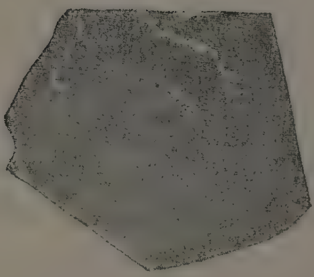

b

FIGURE 12. Sulfide-calcareous concretions with chalcopyrite bloom (white areas) in greenish-gray argillite.

Dzhezkazgan, Pokro mine, Deposit Pokro 8, Horizon 230, Drift 9, Chamber 9. Photograph of polished section magnified 1.5 times.

fissures and the surfaces of the concretions. The width of these veinlets is on the order of fractions of a millimeter.

Pure sulfide concretions have been found in the Pokro-southwest district, in the core from drill hole No. 3311, at a depth of 314 meters; they occur in an ore-bearing dark gray fine-grained sandstone containing thin layered segregations of chalcopyrite; the rock contains much finely dispersed plant detritus that is visible under the microscope.

The largest concretion, whose shape is globular, is shown in Figure 13; this was originally ellipsoidal, but in the polished section of the ore lump it acquired the shape of two adjoining globules, so that the outer contour of the concretion is a fairly complicated curve. The long dimension of the concretion coincides with the layering of the surrounding rock; its greatest dimension is 12 millimeters. The concretion is of the diagenetic type; the layers of rock above and below clearly bend around it, and the intervening layers at the middle of the concretion bend to the left and right.

The internal structure and composition of the concretion, as may be observed under the microscope, are very complex. The kernels of both parts of the concretion consist of collomorphic chalcopyrite with polygonal and ramous desiccation fissures; the latter are filled with collomorphic pyrite which also forms an outer shell around the concretion with a small admixture of chalcopyrite. The pyrite shell contains separations of round particles up to 1 millimeter in diameter, formed of collomorphic bornite with a complex network of desiccation fissures filled with chalcopyrite; these portions are, as it were, tiny concretions forming inclusions within the larger matrix-concretion.

It is interesting to note that the outer surface of the pyrite shell in places has rectilinear crystallographic faces that form the angular and ridge-like projections typical of pyrite concretions. In places the outer surface of the body of the concretion is touched by larger segregations of chalcopyrite (and more rarely chalcosite) of crystalline composition that are clearly distinguishable from the colloidal sulfides typical of the interior of the concretions.

In the same ore lump one may observe still smaller concretions no more than 2 to 3 millimeters in diameter; these are slightly elongated along the layering of the enclosing rock and are composed of dense aggregates of collomorphic bornite and chalcopyrite, sometimes with an admixture of chalcosite along the periphery. In some places the tiny concretions form small chains parallel to the rock's layering, sometimes among the layered segregations of chalcopyrite.

Sulfide concretions, nodules, lumps and clots are rather widespread in the deposits of the Dzhilandinskaya group (Airambay, Saryoba, Kipshakpay and others), located in the bottom part of the Dzhezkazgan suite and occurring north of Dzhezkazgan, along the northern margin of the Dzhezkazgan trough.

The concretionary sulfide formations here have ellipsoidal, lenticular, bean-like and more rarely irregular shapes (Fig. 14). They are usually encountered in the ore-bearing fine-grained sandstones and siltstones. Their long axes are up to 3-5 centimeters in magnitude.

Within the enclosing rock the concretions are usually disposed conformably to the rock's stratification and elongated in the

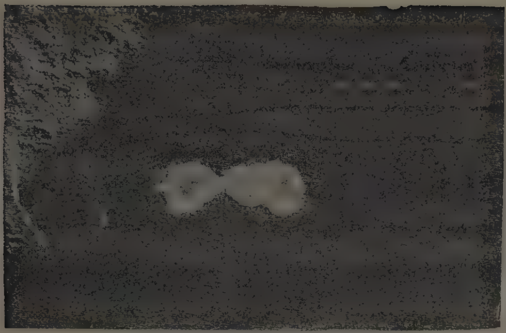

FIGURE 13. Sulfide concretion in the form of globular formations (white) in dark gray ore-bearing fine-grained sandstone containing layered segregations of chalcopyrite.

Dzhezkazgan, Pokro district — southwest, Drill Hole 3311, depth 314 meters. Photograph of polished section magnified 2 times.

direction of the bedding; the latter rounds them, indicating that the concretions belong to the diagenetic type. The boundaries between the concretions and the surrounding rock, which are usually marked by a disseminated sulfide bloom, are fairly clear; the clots form a gradual transition within the ore bloom but they are also quite clearly distinguished against the background of the enclosing rocks.

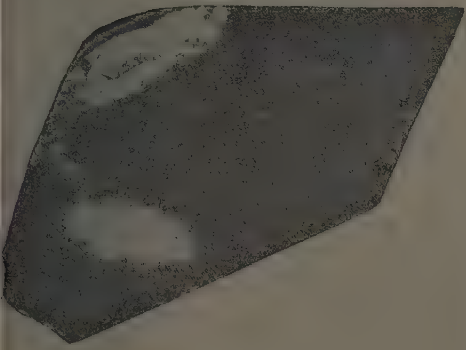

FIGURE 14. Chalcosite-bornite concretions (white) in dark siltstone.

Dzhezkazgan region, Airambay deposit (Dzhilandinskaya group). Photograph of polished section is 4/5 natural size.

The concretions consist either of solid copper sulfides (bornite or chalcosite), or else of nodules and clots of such sulfide bloom in the surrounding rock. Sometimes the nodules are formed of a close net of fine, branching sulfide veinlets, or of a dense bloom of sulfides unevenly distributed within the concretion. The monomineralic concretions have a uniform internal structure; the distribution of the mineral zones in concretions of compound compositions is various. The central parts of some concretions are composed mainly of bornite, which along the periphery is gradually replaced by chalcosite, thus forming an outer shell. In others, on the other hand, the core consists of chalcosite and the outer shell of bornite. Frequently the concretions are composed entirely of chalcosite.

Of particular interest are the carbonate septarian concretions from the Kipshakpay deposit in the Dzhilandinskaya group. Here the concretions are limited to a specific stratum of gray sandstones in the narrowly stratified ore-bearing group of rocks, to which all the cupriferous sandstones of this group belong and which has been called "the stratum of sandstones with calamite." As a result of weathering and disintegration of the stratum containing the concretions, the latter are separated from the arenaceous material embracing them and are freed to accumulate on the surface. They usually have fairly regular ellipsoidal shapes and are of good

size — some 20 - 25 centimeters — along the long axis (Fig. 15); they are composed of a dense, dark pelitomorphic carbonate mass with concentric and radial desiccation fissures that are filled with light-colored calcite of two generations of crystalline composition. The radial mineralized fissures gradually diminish in thickness toward the periphery of the concretions and wedge out before they reach its surface. Under great magnification, within the carbonate body of the concretions one may see an abundance of very fine plant ooze and a thinly dispersed fine bloom of chalcosite, which in places forms clots and nodules. The calcite veinlets also contain chalcosite as infrequent but larger segregations that are undoubtedly formed by redeposition of the chalcosite bloom within the concretion.

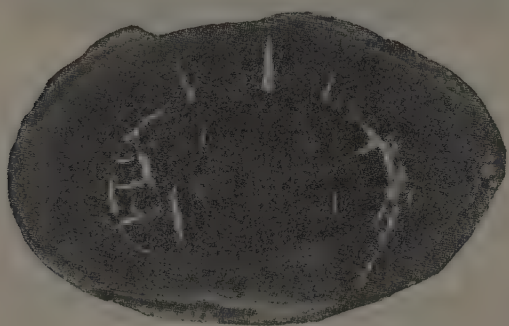

FIGURE 15. Septarian carbonate concretion with desiccation cracks filled with calcite (white) containing chalcosite bloom.

Dzhezkazgan region, Kipshakpay deposit (Dzhinlandinskaya group). 4/5 natural size.

The existence within this type of concretion of copper sulfides both in the main carbonate substance making up the body of the concretion and in the vein calcite filling the internal desiccation fissures, as well as the aging of the colloidal substance, without any doubt testifies to the enrichment of the primary sediment with copper and to its participation in all the diagenetic alterations of the sediment.

* * *

The variety of diagenetic phenomena considered above in the ore-bearing rocks of the Dzhezkazgan suite are of extremely great importance in explaining the actual nature of the Dzhezkazgan ores, inasmuch as all the complex diagenetic processes involve the primary ore material together with the sediments around it. Even in the manifestations of diagenesis, without touching on the still later process of epigenesis and metamorphism, one can clearly see the primary sedimentary nature of the ores; this question can be settled even without drawing upon many other available proofs.

T.A. Satpayeva [5, 6], in insisting on a hydrothermal origin for the Dzhezkazgan ores, essentially avoids the problems of their diagenesis or oversimplifies them, reducing all the manifold diagenetic changes in the rocks of the Dzhezkazgan suite to a mere consolidation of the sediments and their cementation, paying no attention to the behavior of the ore material during all these changes.

In speaking of the known sedimentary cupriferous sandstone deposits of the Donets Basin, the Western Urals region and the Atbasar-Tersakkan region, T.A. Satpayeva takes note of the peculiar forms assumed within these deposits by occurrences of pyrite and chalcosite in the form of collomorphic nodules, globules, clots, etc., as characteristic indications of primary sedimentary ores. Nevertheless the occurrence of very similar formations described by the present writer has been established in the Dzhezkazgan ores and the deposits of the Dzhilandinskaya group, which she has also considered to be hydrothermal. Consequently this typical indication exists

also in the deposits mentioned as "hydrothermal".

Moreover, in erroneously relating the history of ore deposition in Dzhezkazgan, T.A. Satpayeva includes in her "fivefold" resolution, redeposition and recrystallization of the copper as well as the copper sulfate observed by the present author, which was carried from the zones of oxidation of the copper deposits into the zones of erosion, as well as the copper of the carbonates, in which form it was transported by carbonate-bearing streams of water before they flowed into the basin. Since T.A. Satpayeva can no longer pass over the processes of diagenesis and epigenesis in silence, and since she acknowledges that the metamorphism of the Dzhezkazgan ores was slight, the "fivefold" redeposition of the copper, even without the forms of which the copper was carried before being fixed in the sediments, turns out to be not so very great.

In the course of the long-lasting and complex processes of diagenesis, without speaking of the later alterations of the ore associated with the stages of epigenesis and metamorphism, the ore material brought into the sediments was in continuous movement, and there can be hardly any doubt of its repeated resolution and redeposition within the ore-bearing strata, as long as one approaches these natural phenomena from the proper methodological standpoint and considers the material to be in constant and varied movement.

In touching on the diagenesis and epigenesis in the sedimentary series, T.A. Satpayeva acknowledges that "there may have been a whole series (italics mine — V.P.) of solutions, reconcentrations and recrystallizations of the substance with the creation of newly formed sediment, mainly in the cement." Under these circumstances it is hard to understand why T. A. Satpayeva disputes the possibility of a repeated redeposition of the copper over the course of a long interval of geologic time (from the Middle Carboniferous!) during the processes of diagenesis, epigenesis and metamorphism, not to mention the changes undergone by the ores as a result of the repeated fluctuations in the ancient level of the underground waters that were connected with epeirogenic movements. Such inertness and immovability on the part of the ore material is impossible to conceive.

There is also general recognition of the repeated redeposition of the copper sulfides in Dzhezkazgan along the tectonic fractures, which were repeatedly renewed by the occurrences of later tectonic movements after the main stages in the formation of the deposits had already come to an end.

T.A. Satpayeva [5] asserts that in Dzhezkazgan the fine-grained sandstones rarely contain any ore mineralization, or very little, and that the siltstone and argillite rocks are completely without ore. This is not true: the manifestations of diagenesis characterized above by the present writer are often associated with such fine-grained rock, which frequently contains very rich ore mineralization (Figs. 1-5); it is only these very rocks that could preserve the most completely primary diagenetic ores with all the features of structure and texture described above.

6. CONCLUSIONS

1. The ore minerals in the ore-bearing rocks of Dzhezkazgan, being a component of the primary sediment, fully shared the fate of the latter in all the processes of sedimentation, diagenesis and epigenesis. Together with the other components of the sediment, the sulfides were involved in the formation of the bedding structures and helped to determine their nature and varieties.

2. The diagenetic dislocations of the bedding and stratification of the enclosing rocks, as may be clearly seen from numerous illustrations, evidently followed the ore emplacement; the ore minerals and the ore-bearing layers took part in all these dislocations together with the surrounding rocks, and fragments of the ores enter into the composition of the interformational breccias.

3. The breccias described in this article may be classed as ruptural and slide breccias. They originated under the conditions of a shallow-water basin, which underwent oscillatory tectonic movements, as a result of which the bottom sediments were periodically raised above the sea level. The formation of the breccias themselves is closely connected with the gravitational slippage and sliding of the semi-indurated sediments along the sloping bottom of the basin.

4. The appearance in the Dzhezkazgan ores, particularly in the interformational breccias, of thin mineralized fissures of the "Alpine vein" type is related to later stages of alteration of the primary sedimentary diagenetic ores; these stages are associated with epigenesis, dislocational metamorphism and the initial stages of general regional metamorphism.

5. The sulfide mineralization in the above-described layered varieties of ores in the sedimentary breccias and the metamorphic veins of the "Alpine" type are not accompanied by any thermal alteration around the ores, and the surrounding rocks show no reaction to the

sulfides; they are merely color-leached through the transformation of ferric oxide into ferrous under the reducing conditions of sulfide formation.

6. The association of the sulfide mineralization with the massive fine-grained rock, which is water-impermeable and often structureless and unlayered (as in the case of argillites and indurated clays), excludes the possibility that the sulfides could have been carried into them by hydrothermal solutions; such rocks are usually considered to be impenetrable to ore-bearing solutions.

7. All the above-cited facts are convincing testimony of the primary sedimentary nature of the ores of Dzhezkazgan.

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ON THE UPPER CRETACEOUS IRON ORES IN THE EASTERN PART OF THE WESTERN SIBERIAN LOWLAND[1]

by

T. I. Gurova and Ye. G. Sorokina

The iron ores in the eastern part of the Western Siberian Lowland were first discovered in 1950, in the Kolpashevo rayon of the Tomsk oblast', in the course of regional deep drilling. Somewhat later, in 1952-1953, they were discovered in the Narym rayon, and in 1956 in drill cores along the Ket', Vasyugan and Yeloguy Rivers.

The iron ores at all the above points are associated with an arenaceous and argillaceous series of sediments of Upper Cretaceous age.

* * * * *

Over the greater part of the territory under consideration (the Kolpashevo and Narym districts), the Upper Cretaceous iron ores are represented by two strata, of which the lower has the more distinct boundaries and the upper consists of an interlayering of ore beds with oreless rocks. Along the Vasyugan and Yeloguy Rivers, only the lower ore stratum has been discovered, and along the Ket' River, in Tertiary (Eocene) deposits, one more stratum has been found that is not encountered in the other districts.

The lower ore stratum is dated Turonian on the basis of the identified foraminifer fauna in the surrounding rocks of the Narym rayon and the lower reaches of the Vasyugan River. The following foraminifera have been identified: Haplophragmoides sibiricus Zasp., Haplophragmoides kirki Wickenden, Ammodiscus parvus Zasp., Ammobaculites uvaticus Bulatova, Guadriyna filiformis Bert.; throughout the Lowland these are characteristic of the Turonian.

The upper ore stratum occurs in deposits of the Senonian stage, which at the present time cannot be subdivided in greater detail. In the upper part of these deposits Maestrichtian-Campanian (?) foraminifera have been encountered, among which the following have been identified: Bulimina rosenkrantzi Brot., Spiroplectammina kasanzevi Dain., Reusella minuta Marsson, Cibicides pocuriensis Kisselman, Cibicides globigeriniformis Neck. var. compressa Neck. In the lower part of the section through the Senonian deposits, only along the lower reaches of the Vasyugan River, Upper Santonian foraminifera have been discovered: Proteonina sherborniana (Chapman), Proteonina difflugiformis (Brady), Spiroplectammina variabilis (Neck.), Ammobaculites subaequalis Mjatl., Ammobaculites aggutinans (Orb.), Ammodiscus incertus (Orb.).

THE LOWER ORE STRATUM

This stratum, occurring in the Turonian deposits, is the most wide spread in the territory under consideration. The lithologic and mineral composition of this stratum and its enclosing rocks have been most thoroughly studied along the lower reaches of the Vasyugan River. Here a definite succession in the stratification of the Turonian deposits has been established.

At the base lies a light-gray, argillaceous, micaceous, weakly cemented siltstone, the upper portion of which contains thin interbeds of greenish-brown and dirty green sandstone with leptochloritic oolite inclusions, cemented by an argillaceous leptochlorite material, and of a dense argillaceous leptochlorite rock with rare oolites of hydrogoethite and glauconite. This is overlain by the beds richest in iron ore — the ore layer proper.

Macroscopically, the iron ore resembles a dark brown, hydrogoetite, dense oolitic rock, poorly sorted at the bottom and fine-grained at the top, cemented by a ferruginous and ferruginous-chloritic material. Toward the

[1] O verkhnemelovykh zheleznykh rudakh vostochnoy chasti zapadno-sibirskoy nizmennosti.

top it acquires a greenish-brown and dirty green color, becoming less dense and grading into a hydrogoethite-leptochlorite and then into a leptochloritic oolitic iron ire with a leptochlorite cement. The lower ore stratum usually terminates at the top in an argillaceous siderite with rarely occurring pseudo-oolitic leptochlorite (?), or cryptocrystalline siderite with leptochlorite, glauconite and quartz. The siderite is up to 2 meters thick.

The transitions from one bed in the ore stratum to another are usually gradual: the dirty green leptochloritic ores grade into more solid and then into very dense dark brown hydrogoethite ores, which in turn change downward into an argillaceous leptochloritic rock in which the amount of oolites decreases; still lower they are present in the form of inclusions and in approximately equal quantity as the clastic material. At the base of the series, the sandstones with hydrogoethite oolites are interlayered with light gray fine-grained sandstones and mica-bearing argillaceous siltstones.

The thickness of the lower ore stratum along the lower reaches of the Vasyugan River is about 20 meters, and the iron-rich ore stratum proper (together with its siderite cap) is no more than 8 meters thick.

A similar structure of the lower ore stratum is observed in the Narym district, southeast of the Vasyugan River mouth. Here the base of the ore stratum is composed of a fine-grained polymict light gray sandstone with argillaceous cement, toward the top of which leptochlorite appears as oolites and solid masses. This is overlain by the hydrogoethite oolitic ore, grading upward into leptochlorite-hydrogoethite. Here the top layer of siderite has not been found. The total thickness of the ore stratum in the Narym district is about 14 meters. Still farther south, in the Kolpashevo district and beyond, the lower ore stratum is widespread; its stratigraphic succession here is similar to that in the Vasyugan River district, the only difference lying in the fact that all the rocks are more coarse-grained.

The base of the lower ore stratum in the Kolpashevo district is a greenish-gray fine-grained argillaceous sandstone interbedded with brown gravel and gritty conglomerate, held together by a hydrogoethite and partly by a siderite cement, grading upward into a polymict sandstone with various grain sizes and a considerable amount of hydrogoethite and leptochlorite oolites. Above this follows a dark brown, almost black, very dense oolitic hydrogoethite ore, some interlayers of which have a dirty green cast explained by partial chloritization of the ores. The dense oolitic hydrogoethite ore is observed to contain interbeds of poorly sorted, dirty green, weakly cemented leptochlorite rock, enriched with an argillaceous and sometimes sandy material and containing grit and gravel. The ore stratum is capped by dense brown cryptocrystalline siderite containing rare oolites of hydrogoethite.

The total thickness of the lower ore stratum is the Southern Kolpashevo area is 10 to 12 meters.

The lower ore stratum has also been discovered by columnar drilling along the lower reaches of the Ket' River, where its thickness is considerably curtailed so that it is merely an interbed of oolitic hydrogoethite-leptochlorite ore (with an admixture of up to 10% of clastic matter), cemented by siderite and leptochlorite. The ore stratum occurs in a series of greenish-gray, fine-grained micaceous and weakly cemented sandstones.

An interbed of hydrogoethite-leptochlorite oolitic ore has also been discovered considerably farther to the north, along the middle reaches of the Yeloguy River. Here the thickness of the ore stratum decreases to 0.5 meters. It was determined by microscope studies that the basic mass of this rock is composed of oolites, some 0.2-0.8 millimeters and sometimes up to 1 millimeter in diameter, with spherical or ellipsoidal shapes and consisting entirely of either hydrogoethite or leptochlorite. Quite frequently there is an alternation of leptochlorite and hydrogoethite shells within the same oolite. The oolites make up 60% to 70% of the rock. The clastic material (up to 10% of the rock) is represented by colorless subangular fissured grains of quartz and more rarely of felspar. The cement, which amounts to 20% to 30% of the rock, is a combination of leptochlorite, calcite and siderite, in which the carbonate is predominant. Certain parts of the rock are permeated with iron hydroxides.

In summing up what has been said above we are led to the conclusion that the lower ore stratum is rather widespread. Its most distinct boundaries, and also the greatest concentration of iron in the ores, are located in the Kolpashevo district and to the south. Northward the lower ore stratum descends considerably in depth and interbeds of argillaceous and arenaceous rock appear in its base, although the general sequence in the stratification is maintained.

THE UPPER ORE STRATUM

This stratum, which occurs in Senonian deposits, extends laterally within smaller and less distinct limits than the lower. The

Senonian deposits in the Kolpashevo and Narym districts contain two interbeds of ore, of which the lower is made up of a dirty green, friable leptochloritic rock of small thickness belonging to the Coniancian-Santonian deposits; at particular intervals this grades into a hydrogoethite oolitic iron ore. Toward the north this interbed disappears completely and is replaced by glauconitic sandstones. The greatest interest attaches to the Upper Senonian ore interbed (Campanian-Maestrichtian).

In the Kolpashevo district and farther south, the upper interbed of the upper ore stratum has the following structure. At its base lies an evenly medium- and fine-grained, greenish-brown, poorly cemented quartz-leptochlorite sandstone. Upward in the section the sandstone is enriched with hydrogoethite oolites and becomes dark brown, almost black, grading into a hydrogoethite oolitic iron ore of considerable thickness (on the order of 18 meters). At particular intervals this grades into a weakly cemented leptochlorite rock occasionally much enriched with argillaceous material, and into a yellowish brown clay with rare inclusions of leptochlorite oolites. The upper ore stratum ends with a grit and gravel conglomerate cemented with limonite, grading at certain intervals into a poorly sorted polymict sandstone with ferruginous cement. Both the upper and lower boundaries of the upper interbed of the upper ore stratum are quite distinct.

North of the Kolpashevo district, at Narym, the upper interbed of the upper ore stratum has a somewhat different structure. Its base is a layer of dense brownish-gray sandy siderite with oolites of leptochlorite and hydrogoethite; this is followed above by polymict fine-grained sandstones with inclusions of leptochlorites, at particular intervals grading into glauconitic sandstones. Still farther upward the sandstones are gradually enriched with oolites of leptochlorite and hydrogoethite, sometimes grading into an oolitic iron ore of considerable thickness. Farther north, in the Vasyugan area, the upper ore stratum has not been encountered.

In the drill cores from the Ket' River the upper ore stratum occurs in a series of light-gray, felspathic-quartzitic fine-grained sandstones and siltstones, as an interbed of dark brown, almost black dense hydrogoethite ore, which is replaced in the center by a greenish-brown and dirty green weakly cemented leptochloritic rock.

Thus the upper ore stratum extends mainly through the Kolpashevo district and to the south, where its greatest thickness occurs. Northward one observes a considerable decrease in the iron content of this stratum, the iron being replaced by clastic rock enriched to varying degrees with hydrogoethite oolites, which are interlayered with glauconitic sandstones and cryptocrystalline siderite (at Narym). Thereafter the stratum disappears completely and gives way in the direction of its trend to thin interbeds of glauconitic sandstones.

It should be noted that along the lower reaches of the Ket' River, among the Eocene deposits (whose age is determined by pollen-spore assemblages), one more interbed of iron ore of small thickness has been encountered. This is interbedded with a fine-grained dense sandstone, cemented by a cryptocrystalline siderite material, in which the inclusions of ferruginous oolites amount to 40% of the rock.

THE MINERAL COMPOSITION AND THE TYPES OF THE ORES

The following types of ores, as described below, can be distinguished in the upper and lower ore strata, from the standpoint of mineral composition and structure.

1. Hydrogoethite oolitic ores are fairly widespread in both the upper and the lower ore strata. Macroscopically this is a dark brown, almost black, solidly cemented oolitic rock, usually evenly fine-grained but sometimes also of non-uniform granulometric composition. There are different relationships between the cement and the oolites. Most frequently the oolites are closely concentrated, directly touching each other; sometimes they are scattered, so that a considerable part of the rock is made up of the cementing substance. Hydrogoethite, the chief mineral of this type of ore, forms oolites and pseudo-oolites and is encountered as dense masses in the composition of the cement.

It can be seen in thin sections that the oolites of hydrogoethite have a concentric shelled structure. At the center there is frequently a nucleus of magnetite, or a grain of quartz, around which the hydrogoethite shells have grown. Usually the oolites are made up of a homogeneous mineral mass, but in certain cases one may observe crusts of leptochlorite around the periphery.

Hydrogoethite is more rarely encountered in the form of pseudo-oolites. The pseudo-oolites have regular oval shapes, consisting of a dense cryptocrystalline or amorphous mass of hydrogoethite, and are translucent only around the edges. Sometimes along the edges of the larger pseudo-oolites one may observe desiccation fissures (?) filled with leptochlorite. The sizes of the oolites and

pseudo-oolites usually vary within the limits of 0.1 to 0.5 millimeter, but sometimes reach 1 millimeter in diameter. They are cemented by a hydrogoethite-leptochlorite substance forming a homogeneous brown and greenish-brown mass. Most frequently this cement makes up 10% to 15% of the entire mass of the rock. In certain parts of the cement one may observe fissures usually almost perpendicular to the surfaces of the oolites.

Sometimes the cement has been found to contain cryptocrystalline siderite, and the interstices between the oolites are filled with siderite that has a radiating acicular structure. In particular instances the basal microcrystalline siderite cement forms as much as 40% of the rock. The hydrogoethite oolitic ores contain virtually no admixtures of clastic matter, although in rare cases they contain up to 10% of angular grains of colorless quartz.

On the basis of chemical analyses of the hydrogoethite oolitic ores, the following iron contents have been found in them (in per cent): FeO — 4.12 to 11.8; Fe_2O_3 — 21.0 to 39.04; total iron content 22.0% to 48.04%. In individual specimens (from the area south of Kolpashevo) the total content of iron is as great as 63.4%.

2. The leptochlorite oolitic ores have a limited distribution and are associated chiefly with the middle part of the lower ore stratum in the Vasuygan and Narym River districts. Macroscopically, this is a greenish-brown or dirty green, uniformly granular, oolitic rock with various degrees of cementation down to friable. Thin sections show that the spherical and ellipsoidal oolites have a concentric structure and are no more than 5 millimeters in diameter.

Usually the center consists of a dense brownish-green mass of leptochlorite, which may possibly be partially replaced by hydrogoethite, and the outer shells are composed of a lighter-colored concentric leptochlorite. There is almost no clastic material in such rocks. The cement is a cryptocrystalline, semi-transparent dirty green mass of leptochlorite forming up to 20% of the rock; in some cases this is permeated with iron hydroxides. Here and there plant tissues are present in the rock.

The quantitative ratios of ferrous to ferric oxides differ considerably in the leptochlorite as compared to the hydrogoethite ores. Chemical analyses of these ores have revealed the following contents (in per cent): FeO — 28.41 to 31.67; Fe_2O_3 — 10.9 to 14.3; total iron content 38.00% to 45.48%.

3. Hydrogoethite-leptochlorite oolitic iron ores occur extensively in both the lower and the upper ore strata. In composition they are intermediate between the two types just described above, and they usually form interbeds between them. This ore is a brownish-green, sometimes dirty green rock of medium density, with brown and yellow-brown spots and a considerable admixture of clastic material. The sizes of the oolites and the clastic material range from 0.1 to 1.0 millimeter, but are most frequently 0.3 to 0.5 millimeter.

In thin sections it appears that both leptochlorite and hydrogoethite are contained in the oolites and pseudo-oolites, but that the relationships between these minerals and their combinations are extremely varied: in some cases the oolites consist entirely of leptochlorite or else hydrogoethite; in other cases one mineral is wholly or partly replaced by the other. There are frequent oolites with concentric-globular structures in which the core is composed of hydrogoethite and is surrounded by alternating outer shells of leptochlorite and hydrogoethite. The boundaries between these shells of different mineral composition are distinct, but sometimes they are diffuse. Some of the oolites have been observed to have only two shells — an inner one of hydrogoethite and an outer one of leptochlorite. In these ores there is usually clastic material, whose content varies within fairly wide limits, but is usually no more than 15% to 20%.

The greater part of the fragments consists of colorless subrounded quartz grains. Fragments of silica and quartzites are encountered considerably less often. The cement in such rocks is usually a mixture of leptochlorite and siderite; its internal texture is that of a cement filling the interstices — basal, and rarely porous. The siderite in the cement is cryptocrystalline, with a rarely occurring radial variety. The leptochlorite is a semi-isotropic, sometimes fully isotropic dirty green mass with inclusions of mica flakes.

Chemical analysis of the leptochlorite-hydrogoethite ores has shown considerable fluctuations in the percentage content of iron: FeO — 5.40 to 25.65; Fe_2O_3 — 13.80 to 27.63; total iron content 29.92% to 41.30%.

The oolitic ores are gradually enriched both in the vertical direction and laterally by a sand-and-clay substance and grade into ferruginous clay and sandstone, in which the clastic material is accompanied by a smaller or greater quantity of leptochlorite and hydrogoethite with a ferruginous cement. This gradual lateral replacement can be traced in both the lower and the upper ore strata north of the Kolpashevo district. Sometimes one

may note a gradual increase in the amount of argillaceous cement, and the iron ore grades into an argillaceous rock with rare ferruginous oolites.

4. The argillaceous-leptochlorite-hydrogoethite rocks make up a brownish-green and pale green mass with an admixture of leptochlorite, in which there is a random scattering of ellipsoidal and spherical pseudo-oolites of hydrogoethite and leptochlorite up to 0.5 mm in diameter. The hydrogoethite is frequently present in the form of pseudo-oolites, with cracks along the edges that are filled with leptochlorite and siderite. The inclusions of hydrogoethite and leptochlorite make up some 30% of the rock. Certain parts of the thin section reveal round and blade-like grains of glauconite. The pelitic mass often contains scattered plant detritus and remains of plant tissues, which give the rock a brownish tinge.

5. The arenaceous hydrogoethite-leptochlorite rocks usually take the form of unevenly fine- and coarse-grained, less often fine-grained polymict sandstones with oolites of hydrogoethite and leptochlorite in a leptochlorite-siderite and argillaceous-chlorite cement. The sorting of the clastic material in them is fairly poor, and the particles range in size from 0.08 to 0.6 millimeter, rarely reaching 0.6 millimeter. The grains have irregular shapes and are subangular and subrounded, rarely prismatic. Most of the fragments are watery-translucent quartz grains (50-70%), often with numerous "point-like" inclusions. The felspars are represented by brownish peliticized subrounded and rarely tabular grains, making up from 10% to 25% of the amount of clastic material. There is a constant occurrence of fragments of silica, quartzites and rare chloritized flakes of biotite.

The grains in the fine-grained sandstone usually do not exceed 0.3 millimiter in diameter; the ratios between the rock-forming minerals are similar to those described above. In particular individual varieties of sandstone quite a large number of accessory minerals have been noted, among which epidote and magnetite occur with special frequency. Along with the clastic material there are ferruginous ellipsoidal and spherical formations, which make up from 5% to 40% of the rock. These include oolites with a clear concentric structure, sometimes with a quartz grain at the center. More often one observes oolites in incipient form, with a core of magnetite or quartz and one shell of either leptochlorite or hydrogoethite. Hydrogoethite and leptochlorite pseudo-oolites are fairly widespread.

The relationships between the hydrogoethite and the leptochlorite in the rock are various: in some cases the leptochlorite predominates and in other cases the hydrogoethite formations, ranging from 0.1 to 0.7 millimeter in size. The cement in the sandstones, which forms from 10% to 30% of the rock, is hydrogoethite-leptochlorite, leptochlorite-siderite and argillaceous-chloritic. In the fragments one observes pellicular, porous cement, cement which allows the particles to touch each other, cement filling the interstices and rarely basal cement. Sometimes the leptochlorite-hydrogoethite cement contains cracks filled with cryptocrystalline siderite.

Siderite is usually of secondary importance in the cement. Fairly frequently the rock contains siderite with a radiating acicular structure. In addition, the siderite may be present as a microcrystalline variety, and sometimes rhombohedral grains are observed.

Chemical analyses show the following contents of iron in the arenaceous-hydrogoethite-leptochlorite rocks (in percentages): FeO — 5.10 to 6.6; Fe_2O_3 — 7.87 to 11.09; total iron content 10.63% to 11.72%.

6. The gravellite with hydrogoethite cement has a fairly limited distribution and appears in the lower and upper strata in the Southern Kolpashevo area. Macroscopically, the gravellite is a poorly sorted, brown, coarse-grained rock with inclusions of gravel size. The clastic part of the rock consists of well-rounded circular and flat fragments of quartz, quartzites and silica ranging from 1 to 6 millimeters in size. The clastic material is usually fractured by tiny fissures running in various directions, along which the leptochlorite and hydrogoethite appear. The cement is a dark brown, opaque mass of hydrogoethite, in which hydrogoethite oolites occur here and there as inclusions. In some parts of the rock the cement is microcrystalline siderite.

7. The siderite ordinarily occurs at the top of the lower ore stratum, and sometimes forms small interbeds from several centimeters to 2 meters thick in both the lower and the upper ore strata. In thin section the siderite appears to have a cryptocrystalline structure; its texture is massive. Most of this mass is composed of very tiny (less than 0.01 millimeter), brownish grains of siderite. The carbonate mass contains scattered oolites with diameters of up to 0.25 millimeter and concentric structure, the nucleus usually is hydrogoethite and the outer shell leptochlorite.

In certain parts of the rock the structure is pseudo-oolitic: the round, spherical formations, which are in all probability primary oolites of hydrogoethite, have been entirely replaced by microcrystalline siderite with an

admixture of leptochlorite. Such pseudo-oolites are cemented by lighter-colored microcrystalline siderite.

In other cases the rock is composed of siderite spherulites in the form of rosettes about 0.1 millimeter in diameter, cemented by cryptocrystalline siderite. Frequently the center of the spherulite contains a tiny rhombohedral particle of siderite covered by several alternating shells of darker and lighter cryptocrystalline siderite. The outermost shell is composed of yellowish siderite with a radiating acicular structure.

In the carbonate mass have been encountered occasional fragments of quartz up to 1 millimeter in diameter, the fissures in which are filled with siderite. As much as 5% of the rock may consist of roundish and ellipsoidal oolites of leptochlorite up to 0.3 millimeter in diameter. Individual grains of glauconite have also been found.

Dark brown interbeds of siderite mixed with clay and sand have also been found. In the sandy siderite, the clastic material consists mainly of colorless angular grains of quartz, and rarely of felspars and fragments of argillaceous rock. Up to 25% of the rock is made up of clastic material, the size of whose fragments ranges from 0.03 to 0.3 millimeter, and up to 20% of oval ellipsoidal and irregular grains of hydrogoethite and leptochlorite. Bright green blade-like grains of glauconite are also encountered.

Chemical analysis of the siderite has revealed: Fe_2O_3 — 25.75%, FeO — 7.02%; total iron content ranges between the limits of 24.76% to 40.04%, depending on the larger or smaller content of hydrogoethite and leptochlorite oolites and pisolites.

THE GENESIS OF THE IRON ORES UNDER CONSIDERATION

In a number of papers that consider the genesis of the iron-ore deposits [1, 2, 5], the process of ore formation is intimately connected with the general course of epeirogenic movements of the earth's crust, and is attributed especially to epochs of transgression or regression. Such conditions are also observed in the district investigated by the present author. The Turonian age, with which the richest iron-ore deposits of the lower ore stratum are associated, marks the beginning of the transgression, which encompassed much of the territory of the Western Siberian Lowland.

The iron ores described in this article are typical sedimentary shallow-water littoral-marine formations. Their shallow-water nature is shown by the considerable amount of terrigenous material in them, which is often coarse-grained, and by the remains of plant tissues.

During the whole of the Upper Cretaceous, the facies conditions of sedimentation in the territory under consideration were extremely variable. For example, the absence of the lower ore stratum along the lower reaches of the Vasyugan River is explained by the fact that here the sediments were probably deposited in deeper waters than in the adjacent districts, and in the Santonian there was a formation of mold-like, glauconitic rocks, whereas calcareous deposits were formed in the Maestrichtian-Campanian age. The area was somewhat farther from the shoreline than it was in the Turonian age.

The Senonian in the Narym district shows the same facies variability of the deposits in the section. Mold-like clays and glauconite-containing rocks are developed in the lower part of the Santonian section, but higher up they give way to leptochloritic rocks.

More stable facies conditions obtained in the Kolpashevo district, where throughout the entire Upper Cretaceous there were fairly constant shallow-water littoral-marine facies. Here the iron ores of the upper and lower strata have substantially the same composition.

In the Eocene iron-ore stratum around the lower reaches of the Ket' River, the glauconitic sandstones, which are widespread throughout the region under investigation, are replaced by leptochloritic iron-ore facies east of Kolpashevo. The same thing will probably also be observed in other areas as one approaches the shoreline of the Eocene marine basin.

All this increases our conception of the possibilities for the discovery of new deposits of iron ore.

The main ore components (of the iron ores described here) are the result of chemogenic deposition of iron from aqueous solutions, as many investigators have pointed out [3, 4, 5]. Over the eastern part of the Western Siberian Lowland, throughout all of the Upper Cretaceous, there was a predominantly hot and rather moist climate, which facilitated weathering and migration of the iron on a considerable scale.

The deposition of most of the iron in the near-shore parts of the sea was cyclical, but discontinuous. the first iron was deposited in the Turonian age, and thereafter new portions of iron were periodically deposited through all of Senonian times.

FIGURE 1. Paleogeographic map of Western Siberia in Turonian time:

1 -- Shoreline of the Turonian Sea; 2 -- zone of prospective occurrence of iron ore in the eastern part of the lowland; 3 -- marine facies; 4 -- continental facies.

From the ferruginous gel deposits that were precipitated, iron hydroxides (mainly hydrogoethite) were formed in the near-shore zone, and in the parts of the sea farther from the shore, where slightly reducing conditions existed, leptochlorites and siderites were deposited. In the stage of diagenesis reducing conditions developed to an ever greater extent in the sediments, and the primary material was redistributed.

The leptochlorites developed considerably, replacing the hydrogoethite sometimes in the concentric shells of the oolites, sometimes in their centers and sometimes throughout the entire oolite.

One may observe a partial replacement of the oolites of hydrogoethite-leptochlorite composition by siderite, and siderite cement is widely developed. Certain oolites are fractured by a network of fissures and sometimes have broken edges; this may indicate a partial washing of the ferruginous oolitic ores in the near-shore zone of the sea.

CONCLUSIONS

1. The Upper Cretaceous iron ores in the eastern part of the Western Siberian Lowland are hydrogoethite-leptochlorite-siderite oolitic near-shore marine formations.

2. The ores richest in iron are of Turonian age and extend to a fairly large distance laterally; the depth of their occurrence decreases as one moves toward the east and southeast (Fig. 1).

3. The points at which it has been indicated that iron ores occur testify to the extensive development of facies conditions favorable to their formation throughout the territory of the Western Siberian Lowland in the Upper Cretaceous. Further geologic prospecting should discover industrially valuable deposits of iron ores in this area.

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THE ANCIENT METAMORPHIC ROCKS AND THE METALLOGENY OF THE TIMAN REGION[1]

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The Timan is one of the few tectonic structures of the Russian platform where the exposed cores of structures reveal the relations between the sedimentary mantle and the crystalline basement, and where there is a possibility of subdividing the basement into a sequence of formations. It is suggested that in this very region, more easily than elsewhere, one may solve the question of the time of the last stages in the formation of the basement of the Russian platform. The discovery of placers and ores in schists and veins, the occurrence of weathering crusts and commercial oil- and gas-bearing prospects of the region have attracted geologists' attention still more.

The geology of the Timan is still rather poorly described in the literature. In Tsarist times the Timan, as a distant part of Russia, was investigated by occasional expeditions (A. Keizerling [17], A. Shtukenberk [16], F.N. Chernyshev [14], and others). These expeditions began the study both of the crystalline rocks constituting the basement and of the overlying sedimentary deposits. F.N. Chernyshev's [13] interpretation of the Timan's geology was reflected in all general geologic maps of the European basin. Study of oil prospects in the area also contributed to the knowledge of the geology of the younger strata of the Timan. Up to the time of the October Revolution, however, no great importance was ascribed to the Timan as a source of oil or other mineral resources.

Systematic geologic investigation of the Timan-Pechora region began in the Soviet period and was intensified after 1929. Study of the sedimentary rocks covering the platform, along with prospecting work, resulted in the discovery of the Pechora coal basin and of the Timan-Pechora oil- and gas-bearing province, with its many important oil and gas fields. Oil shale deposits and other mineral reserves were also discovered. But in this work little attention was paid to the metamorphic and intrusive rocks of the Timan. Data on these rocks are found only in few publications (D.S. Belyankin [1], B.V. Miloradovich [11], K.K. Vollosovich [3], A.G. Vologdina and E.A. Kal'berg [5], A.G. Vologdina [4], E.A. Kal'berg [6], V.A. Kalyuzniy [7], D.P. Serdyuchenko [11], and O.A. Solntsev [12]).

The metamorphic rocks of the Timan, forming the basement of the platform, are transgressively and unconformably overlain by Paleozoic strata. Ancient rocks are exposed in the cores of several block-faulted structures and are associated with the uplifted parts of indivdiual structures showing an en echelon arrangement (Fig. 1) extending from Dzezhim-Parma Hill in the southeast to Cheshskaya Bay in the northwest. Exposures of ancient rocks are also found near the village of Ksenofontovo and in the Kolva-Vishera district; but the composition and nature of the rocks exposed in these areas are closer to those of the ancient rocks of the Urals, and are not discussed here.

According to Ye.M. Lyutkevich's investigations [8], Timan metamorphic rocks are also found on the Kanin Peninsula. East of the Southern Timan (east of Och-Parma Hill) and in the Western Pechora region, metamorphic rocks were discovered by deep drilling. Thus the width of the zone of Timan metamorphic rocks investigated reaches 70 to 100 kilometers. Owing to the discontinuity of the exposures, we shall discuss the texture and composition of metamorphic rocks separately for each region. This must also be done because the ancient metamorphic rocks are of great interest for the petrogenesis and ore-bearing prospects of the Timan. A knowledge of these rocks contributes to the understanding of the general mineral-bearing of deep zones of the Russian platform. The data on Timan metamorphic rocks may also be used to correlate these rocks with the rocks of adjacent areas, in the light of the views that the Timan metamorphic rocks are

[1] Metamorficheskiye drevniye tolshchi i metallogenicheskiye cherty Timana.

synchronous with and analogous to the non-metamorphic sediments found on the Russian platform (Redkino, and others). Some workers have surmised that the metamorphic rock outcrops at the Chetlasskiy Kamen' Hill are of the same age as the Burzyantsy and Yurmatintsy series of the Southern Urals.

The author of this article has considered it possible to elucidate thoroughly the available data on the Timan, using the results of many explorations of recent years in which he has been personally engaged.

The Southern Timan. F.N. Chernyshev [14], in his description of the exposures at Dzhezhim-Parma Hill, has already noted that the Carboniferous and Upper-Devonian sediments are underlain by schists and conchoidal dolomites. In 1926, G.N. Ognev (Cf. B.V. Miloradovich [10]) subdivided these rocks lithologically in greater detail. From the bottom upward, he distinguished shales, Dzhezhim beds (sandstones), and conchoidal dolomites. In 1936 this subdivision was confirmed by B.V. Miloradovich [10], who, by analogy with the rocks exposed on the Urals' western

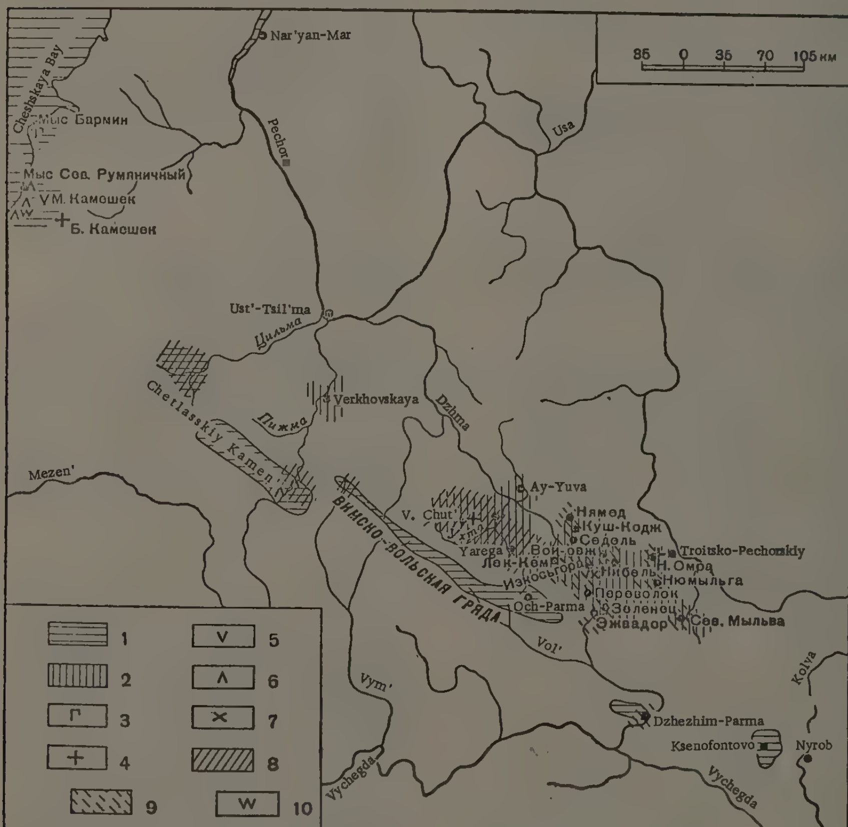

FIGURE 1. General sketch map of the Timan and the area to the east, showing the distribution of metamorphic series and igneous rocks. (Drawn by V.A. Kalyuzhnyy.)

1 -- Areas with exposures of metamorphic rocks; 2 -- areas where metamorphic rocks were discovered by deep drilling; 3 -- gabbro-diabases; 4 -- granites; 5 -- syenites; 6 -- aegirite-syenites; 7 -- quartz-monzonites; 8 -- zones of ilmenite-rutile-bearing schists and of a high degree of metamorphism; 9 -- areas and zones of distribution of weathered crust on schists; 10 -- nepheline syenites.

slope, assigned the lower shale formation to the Lower Devonian and the Dzhezhim sandstones and conchoidal dolomites to the Middle Devonian. In recent years this area has been studied by N. N. Rostovtsev (cf. Ye. V. Vladimirskaya [2]) and Ye. V. Vladimirskaya.

There is a large brachyanticline at Dzhezhim-Parma Hill. Its core is composed of ancient rocks and its flanks of Upper Devonian and Carboniferous deposits. The core itself is the limb of an ancient structure. The ancient rocks constituting this core are exposed along the Asyv-Vozh River, near the village of Churuk at Dzhezhim-Parma, along the left source of the Vil' River and along the Marka-P'yan-Shor and Yshkemes Rivers. In the core of the northeastern flank of the brachyanticline is the Chetlass formation, composed of gray-black micaceous schists which were designated by N. N. Rostovtsev as formation M_1. They are transgressively overlain by the Dzhezhim formation (the Dzhezhim sandstones, according to B. V. Miloradovich; formation M_2, according to N. N. Rostovtsev; or the Rassol'ninskaya formation, according to Ye. V. Vladimirskaya) which dips NE 35° to 50°, < 30° to 60°. The apparent thickness of this formation is 760 meters according to Ye. V. Vladimirskaya and 300 meters according to B. V. Miloradovich. This formation consists of medium-grained yellow, pink, red, and gray arkoses or feldspar-quartz sandstones. At the bottom, the sandstones are interbedded with a conglomerate composed of subrounded feldspar, quartz and shale pebbles up to 0.8 centimeters in diameter. The grain size of the sandstone decreases upward. The chief constituents are quartz (60-90%) and feldspar (30-40%). Orthoclase, microcline and plagioclase are also found, the latter showing various degrees of sericitization. Ilmenite, leucoxene, sphene(?), mica (colorless and brown, partly chloritized), zircon, tourmaline, and magnetite are less abundant. The cement is sericite, clay and iron hydroxides. The heavy residue consists of opaque ore-minerals (50-80%), zircon (10-25%), titaniferous minerals (10-15%) and discrete grains of barite, garnet, epidote, apatite and mica. Spectrographic analysis of the sandstones (Table 1) reveals a high content of zircon and strontium and an absence of copper and chromium (traces), which distinguishes them sharply from the sandstones of Och-Parma Hill.

Higher up in the section is the Bobrovaya formation, 1,350 meters thick. This is the M_3-M_6 formation, according to N. N. Rostovtsev, and the upper part of the Rassol'ninskaya plus the lower part of the Demino formation, according to Ye. V. Vladimirskaya. This formation, well exposed along the Vil' River, is composed of greenish-gray quartz-mica siltstones and shales, the latter often bedded. Ripple marks and sericite flakes are found in the bedding planes. By composition, one may distinguish mica-quartz siltstones with an admixture of feldspar (5-10%), and quartz-mica shales with siderite in places; microscopic bands are observed. Accessory minerals in the shales are zircon, tourmaline, sphene, hematite and ilmenite. A high siderite content (up to 65%) is found in some heavy-mineral residues. Still higher in the column is the Bystrukha formation, 1,000 meters thick. Its lower boundary follows the bottom of the first marl layer. The best outcrops are along the Asyv-Vozh, Yshkemes, Isoru and Voy-Vozh Rivers and others. The lower part of this formation consists of interlayered marls and argillites. These deposits grade upward into gray "algal", more rarely dark bituminous, thick- and thin-bedded conchoidal calcitic dolomites; they are fine-grained, in places silty. In the upper part the dolomites are interlayered with thin-bedded dark-gray marls and bluish-gray argillites. Layers of gray and dark-gray dolomitic limestone and argillite also appear. Where the formation has undergone weathering (Yshkemes River), the rocks have acquired red-brown, lilac, and crimson colors due to the presence of iron hydroxides in fissures and pores. The solubility of the dolomite in hydrochloric acid is 97.4%, and that of the marl is 50-60%. According to Ye. V. Vladimirskaya [2], the organic remains in the algal limestones are Collenia sp. and Gymnosolen sp. N. N. Rostovtsev dates this formation as Middle Cambrian.

In the Och-Parma area, the best outcrops of all four formations are found in the vicinity of Mt. Potchuruk along the Pot'yu, Ras'yu, Pukado-Vozh, and Parma-Vozh Rivers. The lower Chetlass formation, some 1,000 meters thick, is clearly seen at Mt. Potchuruk; its strike is NW 310° to 340° (determined from 13 measurements) and its dip is 35° to 75° NE. This formation occurs in Listan-Sluda and other localities, where it is composed of greenish dark-gray schists, in places plicated, with thin interbeds of light-gray quartzitic siltstones. These are quartz-sericite-chlorite and graphite-quartz-chlorite-mica schists with a lepidoblastic texture. Large penninite flakes occur at the contacts between laminae. In the psammitic interbeds and in the schists, along with fresh albite, are preserved remains of biotite, grading into chlorite with leucoxene grains. Zircon, tourmaline and rutile are also found. The alteration of the biotite to chlorite, with the formation of leucoxene, indicates regressive metamorphism. Fragments and cobbles of gray vein-quartz with drusy rock crystals were found in the stream bed of the Pot'yu River. In the zone of intensive cleavage a vein of gray quartz, 0.3 meters thick, with pyrite inclusions was encountered. Table 2, giving the chemical

Table 1

Results of spectrographic analysis of rock samples from the districts of Dzhezhim-Parma, Och-Parma, Ukhta and Chetlasskiy Kamen' (Bobrovaya River basin)

Formations	No of Samples analysed	Content of elements (in per cent)						
		Cu	K	Na	Ti	Ba	Sr	V
A. Dzhezhim-Parma District								
Dzhezhim (after N.G. Chochia)	8	not exposed	—	1,0	0,1	not determined	0,1	0,003—0,05
B. Och-Parma District								
Chetlass formation	6+	0,005		1,0	0,1	0,001—0,003	none	0,001—0,003
Dzhezhim formation (the Ras'yu River)	2	0,001—0,003	0,003	1,0	0,1	0,001	0,001—0,003	0,001—0,003
Same	5+	0,001—0,005	0,5—1,0	0,5—1,0	0,1	0,01—0,05	0,01—0,05	0,003
Bobrovaya formation	13+	0,001—0,005	0,03	1,0	0,1	0,001—0,003	0,001—0,005	0,003
C. The Ukhta River District (Ukhta, Yarega, Shomvukva)								
Bobrovaya formation, Yarega and Ukhta Rivers	4x	0,0004		0,1	0,7	0,004—0,04	not det.++	0,001
Shomvukva River	2+	0,001—0,003			0,1	0,001	0,005	0,003
D. Chetlasskiy Kamen' Hill. Middle Timan								
Bobrovaya formation, Bobrovaya River basin	4x	0,0001		0,1—0,4	1—7	0,01—0,04	0,01—0,04	0,001—0,01
E. Verkhnyaya Izhma District								
Schists from the areas of Kush-Kodzh, Sedel' and Voy-Vozh	14+	0,001 and less			0,1	0,001—0,01	0,001—0,003	0,001—0,005
Schists from Ezhvador	10+	0,001—0,05			0,1	0,001—0,003	none	0,003

NOTE: Comma represents decimal point.

composition of the schists, shows that MgO predominates over CaO and K_2O over Na_2O. This clearly indicates the sedimentary origin of these rocks. Spectrographic analysis has shown the presence of Cu and Cr and the absence of Sr.

The overlying Dzhezhim formation is 300 meters thick. The best outcrops are found along the Ras'yu River, where the rocks dip some 20° NW. In the lower part of the exposed formation one can see the contact between the dark-gray, plicated, thin-bedded schists of the Chetlass formation and the quartzitic sandstone of the Dzhezhim formation. This sandstone is composed chiefly of tightly cemented quartz grains. There are also albite, chlorite, in the form of thin scales; particles of penninite; rounded grains of zircon and tourmaline; and fine-grained leucoxene. Data from spectrographic analysis (Table 1 show that this formation differs from the Chetlass formation in having a lower Cr and Cu content (0.001%, but in two samples the Cu content was 0.005%), a higher Ni content, and by the presence of strontium, which was not found in the Chetlass formation at Och-Parma.

The Bobrovaya formation, 2,500 meters thick, was distinguished within the Och-Parma suite by O.A. Solntsev. It is exposed on the

Table 1, continued

Content of elements (in per cent)											
Ni	Cr	Pb	Mn	Al	Ga	Zr	Mg	Ca	Si	Fe	Be
A. Dzhezhim-Parma District											
0,01—0,03	traces					0,1—0,3					
B. Och-Parma District											
0,001	0,01										
0,001	0,001										
0,003	0,001										
0,003	0,001—0,003										
C. The Ukhta River District (Ukhta, Yarega, Shomvukva)											
0,001	0,004	-	0,007	>7	0,001	0,01	1—3,0	0,04	>7	0,4	
0,003—0,005	0,001—0,003	0,001									
D. Chetlasskiy Kamen' Hill. Middle Timan											
0,004	0,004—0,04		0,0004—0,001	7	0,004—0,07	0,04—0,1	1—3,0	0,01—0,04	7	0,1—0,4	0,0001—0,0004
E. Verkhnyaya Izhma District											
0,001—0,005	0,001	2									
0,003	0,003										

watersheds of the Post' and Nivshera Rivers and on the slopes of Mt. Nyuy-Nerek-Churuk. This formation is probably analogous to the Och-Parma formation distinguished by K.K. Vollosovich along the Ropcha River. A 100-150 meter thick stratum of schists along the upper reaches of the Ras'yu and Pot'yu Rivers belong to the Bobrovaya formation. These schists lie between the Dzhezhim and Bystrukha formations. They are thin-layered, dark-gray, gray, and occasionally greenish ash-gray. The lower part contains thin flakes up to 1 x 2 meters, and resembles slates. Steeply dipping fissures are filled mostly with calcite, less often with quartz. The minerals in the schists are graphite-quartz-chlorite-mica; they have lepidoblastic and more rarely porphyroblastic textures formed by large particles of penninite. The schist groundmass consists of fine sericite scales, chlorite, and penninite. Quartz, biotite, and pyrite are less abundant. Graphite is either dispersed throughout the rock or occurs in veinlets. Leucoxene (Fig. 2) is present in granules and discrete isometric grains. The accessory minerals are in long prismatic crystals of tourmaline, light-green in color with a yellow zone around the prism, rutile in long columnar prisms, and brownish zircon which is occasionally subangular. The upper part of the formation is composed of quartz-sericite-mica schists with inclusions of hydrogoethite. A white clayey

Table 2

Chemical composition of sedimentary-metamorphic rocks of the southern and middle Timan

District	Formation, name of rock	Content of rock-forming oxides, in per cent																	
		SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	MnO	CaO	K_2O	Na_2O	SO_3	P_2O_5	BaO	F	H_2O^-	H_2O^+	loss on ign.	Total
	A. Basement rocks																		
Dzhezhim-Parma	Bystrukha formation. Dolomites and calcareous rocks +	—	—	0,40	1,36	0,21	19,93	—	30,35	—	—	—	—	—	—	—	—	45,93	98,18
Och-Parma	Chetlass formation. Schist, dark-gray, quartz-chlorite-sericite with granite +	60,14	0,20	19,81	2,12	5,78	0,83	0,02	0,65	3,64	1,76	—	0,07	—	—	—	2,78	2,0	99,80
Zelenets	Chetlass (?). Schist, dark-gray, thin-banded, graphite-quartz-chlorite-sericite, with siderite+	68,23	0,77	13,40	4,04	3,40	1,88	—	0,97	0,41	0,83	0,14	trace	—	—	0,24	—	5,18	99,49
Yarega	Bobrovaya form. Schist, dark-gray, banded, graphite-quartz-sericite-chlorite x	62,96	1,15	18,95	1,43	4,61	1,56	—	0,60	4,04		—	—	—	0,3	0,03	2,92	1,12	99,67
Ukhta	Bobrovaya form. Schist, banded, dark-gray, graphite-quartz-sericite-chlorite +	65,65	0,23	17,34	1,79	3,63	1,30	0,09	0,60	3,68	1,42	—	0,12	0,10	—	trace	3,12	—	99,07
Chetlasskiy Kamen' (Bobrovaya R. Basin)	Bobrovaya form. Schist, banded, gray, quartz-chlorite-sericite, with graphite x	69,13	0,98	18,85	1,39	0,30	0,93	—	0,60	4,76	0,29	—	—	—	0,29	—	1,40	1,33	100,25
		70,52	0,91	17,06	1,24	0,24	0,92	—	0,69	4,59		—	—	—	0,28	0,47	1,40	1,54	99,86
	B. Weathered crust on schists (Verkhnyaya Izhma area) of the Southern Timan																		
Nyamed	Schist, quartz-kaolinite-sericite, with siderite +	59,72	0,11	18,30	1,18	7,82	1,65	0,15	0,92	0,44	0,18	0,64	0,35	—	—	0,99	—	7,10	99,55

NOTE: Comma represents decimal point.

Table 2, continued

District	Formation, name of rock	Content of rock-forming oxides, in per cent																	
		SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	MnO	CaO	K_2O	Na_2O	SO_3	P_2O_5	BaO	F	H_2O-	H_2O+	loss on ign.	Total
Voy-Vozh	Schist, reddish-brown, ferruginous and kaolinized+	60,4	0,52	16,97	11,94	0,18	0,30	none	0,87	3,85	0,53	0,37	0,07	—	—	—	—	4,07	100,07
Same	Same +	66,23	0,10	18,0	5,22	0,46	0,80	.	1,29	0,86	0,03	0,33	1,42	—	—	0,96	—	3,95	99,65
Zelenets	Chetlass formation (?). Schist, grayish-white, kaolinized+	63,01	0,73	20,95	2,73	2,53	1,60	.	0,83	0,35	1,05	trace	trace	—	—	0,40	—	5,53	99,71
C. Unaltered shales (Verkhnyaya Izhma area), not subdivided																			
Nyamed	Schist, siderite-quartz-chlorite +	67,76	0,09	14,78	4,6	4,40	0,55	0,12	0,77	1,0	0,50	0,47	0,72	—	—	0,89	—	3,92	100,57
Sedel'	Schists, sericite-quartz, with an admixture of chlorite +	73,85	0,18	12,58	4,18	—	0,23	0,16	0,59	3,95	1,53	—	0,30	—	—	0,60	2,50	—	100,65
D. Clays of the sedimentary mantle of the Southern Timan (individual packets).																			
Verkhnyaya Izhma District, Sedel'	Upper Zhivetskiy substage, Low Chib'yu strata: a) light-gray clays +	44,82	0,58	26,25	2,09	2,43	2,81	0,09	0,91	0,38	0,26	3,48	0,48	—	—	1,51	—	13,97	100,06
	b) oolitic ironstones +	18,56	0,52	5,35	46,48	9,50	1,71	0,16	2,36	not det.	not det.	2,31	0,37	—	—	1,44	—	10,48	99,24
Same	Lower Frasnian stage, Pashiyskiye strata																		
Voy-Vozh	Greenish-gray rock with siderite concretions +	38,10	0,84	27,75	6,25	6,18	1,41	0,03	1,80	0,38	0,32	2,06	0,23	—	—	0,72	—	13,56	99,63
Ezhvador	Lower Carboniferous a) boehmitic bauxites	25,6		59,6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	85,2
	b) ironstones	—	—	—	45,70	—	—	—	—	—	—	—	—	—	—	—	—	—	—

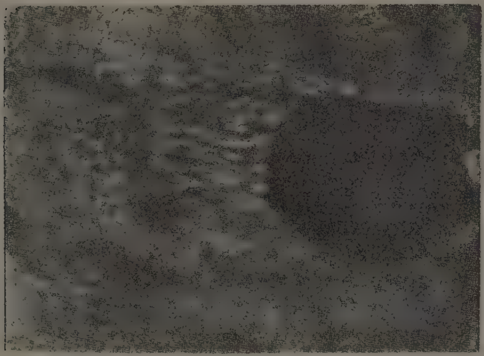

FIGURE 2. Quartz-mica-chlorite schists with leucoxene in isometric grains. Lepidoblastic blastoporphyritic texture. (Och-Parma Hill, Southern Timan).

Magnification 120X.

deposit is occasionally found on the walls of voids formed by leaching.

The Bystrukha formation, with a thickness of 3,500 meters, is found along the banks of the Pukado-Vozh, Ropcha, Lat'yu, Pot'yu, and Voy-Vozh Rivers. K.K. Vollosovich [3] gave the name "Ropcha formation" to the formation under consideration exposed at the Ropcha River, where its thickness is 1,400 meters. O.A. Solntsev [12] called it the Pukado-Vozh formation and determined its thickness to be 3,500 meters. The formation is made up of calcitic dolomites, usually gray and dark-gray in color and containing 0.99% of HCl-insoluble residue. Schist interbeds up to 1 meter thick, occur in the lower part of the formation. The dolomites are characterized by a cone-in-cone texture. The groundmass consists of fine dolomite grains; a black substance, probably of organic origin, is dispersed throughout the rock. Organic remains from this formation, collected by K.K. Vollosovich, were identified as stromatolites of the genus Collenia wolcott, resembling Middle and Lower Cambrian forms [4].

The Chetlass, Dzhezhim and Bobrovaya formations exposed in the Och-Parma area differ from a series exposed in the Dzhezhim-Parma area in the chemical composition of the rocks and are characterized by a higher degree of metamorphism. Apparently the metamorphism of these formations in the Och-Parma area is associated with a deep granitoid intrusion.

Northwest of Och-Parma, a narrow zone of schists is mostly concealed under sedimentary rocks. But on the watershed between the Ukhta and Shomvukva Rivers, and in the upper reaches of the latter river, there occur fragments of thick-layered schists which are tentatively assigned to the Bobrovaya formation. These are chlorite-quartz-sericite schists with a lepidoblastic texture. The chief constituents are sericite in narrow scaly aggregates, interlaced fibers of chlorite, and quartz grains; the minor constituents are albite, brown biotite, greenish and brownish fringed tourmaline and angular sphene grains. In the outcrop at the Kamenets-El Creek, the minerals in the schists are biotite, sericite, chlorite, and quartz; the biotite is partly replaced by penninite. Spectrographic analyses (Table 1) show that the schists of the Shomvukva River do not differ from the schists of the Bobrovaya formation.

East of the Shomvukva River, in the Ukhta River area, metamorphic rocks hidden under sedimentary deposits were encountered by drill holes along two lines. A transverse section along the middle reaches of the Ukhta River (Fig. 3) revealed (from the top to the bottom): the Bobrovaya, Dzhezhim, and Chetlass formations, forming a large anticline whose eastern limb is depressed along a longitudinal thrust. One of the western drill holes penetrated all three formations. The central drill hole passed through the Dzhezhim formation, overlying the Chetlass formation; the upper Bobrovaya formation has been completely eroded here. The eastern drill holes penetrated only the depressed flank and did not go further than the schists of the Bobrovaya formation, having penetrated more than 500 meters of them. Most of the drill holes of the longitudinal section along the Yarega River penetrated the

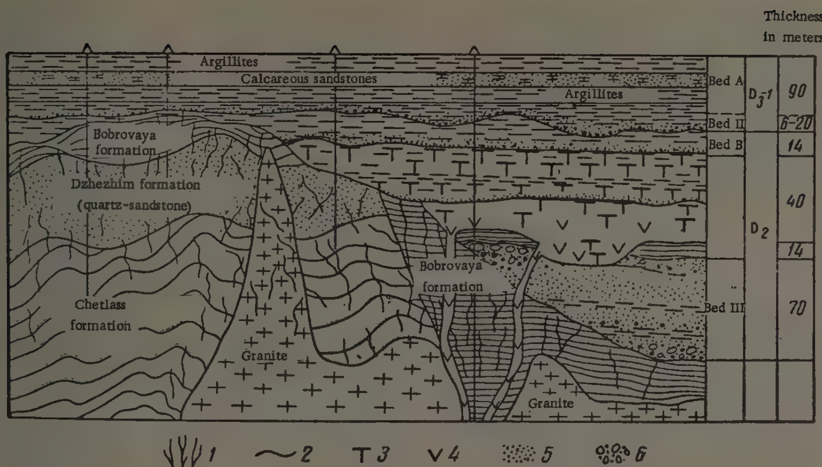

FIGURE 3. Diagrammatic geologic section through Devonian and older rocks in the area of the middle reaches of the Ukhta River (adjusted to a datum plane of the Kynovskiye strata. Compiled by V.A. Kalyuznyy, with data from A.V. Kulevskiy.

1 -- Fissures; 2 -- stratigraphic gaps; 3 -- tuffaceous sediments; 4 -- diabases; 5 -- sands and sandstones; 6 -- conglomerates and accumulations of pebbles.

Bobrovaya formation and part of the Dzhezhim formation; two drill holes passed through the Bobrovaya and Dzhezhim formations and bottomed in the Chetlass formation. The thickness of the Dzhezhim formation reaches 260 meters. The Bobrovaya and Dzhezhim formations are slightly undulating. The Chetlass formation is made up of steeply dipping dark-gray thin-layered quartz-chlorite-sericite-mica schists containing very fine sandy interbeds whose thickness ranges from fractions of a millimeter to 3 millimeters. The thickness of this formation is not established.

The lower part of the Dzhezhim formation is composed of gray quartz conglomeratic and gravelly quartzitic sandstones which grade upward into more fine-grained quartzites and quartzitic sandstones. The conglomerates and gravelly sandstones contain fragments of quartz and of plicated schists from the Chetlass formation. The quartz grains in the quartzites are tightly cemented. The grains of zircon and more rarely of tourmaline are subangular and thus attest to the sedimentary origin of sandstones. Quartz makes up 89 to 90% of the rock; plagioclase No. 14 is much less abundant. Chlorite, a light-colored mica-monazite, in places biotite (with pleochroic halos), and pyrite occur still less often. Some thin sections contain apatite, rutile, anatase, garnet, and plagioclase showing a zonal texture, highly seriticized and calcitized. The sandstones are shattered by an intensive system of nearly vertical fissures. Some of them have veins filled with calcite, quartz, or quartz and feldspar.

The Bobrovaya formation is represented by gently dipping dark-gray graphitic schists, showing a banded texture which is in places plicated. They are made up of alternating recrystallized layers of pelitic, aleuritic and sometimes psammitic composition, altered to schists and quartzites. The schists contain veinlets of quartz with chalcopyrite, galena and sphalerite. Quartz-feldspar veinlets occur less often. Bitumen lines the walls of the fissures, in places forming little spherical bodies; subsequent layers of carbonate cover these walls.

The schists are composed of quartz, chlorite, and sericite; they contain much penninite, ilmenite in prismatic crystals, ilmenorutile and rutile, which are often leucoxenized. Monazite, tourmaline, zircon and albite occur more seldom. The elongated grains of tourmaline are often broken and their parts relatively displaced. The tourmaline columns are mostly parallel to the bedding planes. Prismatic grains of leucoxene up to 0.3 x 0.4 millimeters are parallel or oblique to the schistosity (Fig. 4). In the tension zones of the schists these grains are often broken to pieces and rotated together with the flakes

forming the chlorite-mica fabric. Graphite occurs in disseminated flakes, which in places form concentrations. In the porphyroblasts of chlorite occasional pleochroic halos are preserved around thin ingrowing minerals. The texture of the rock is lepidoblastic and in places porphyroblastic. These schists show evidence of thorium emanations. There are occasional interbeds of the following mineral assemblages: sericite-actinolite and sericite-chlorite-quartz, both with plagioclase, elongated prismatic leucoxenized rutile, ilmenite and graphite.

In the Yarega River basin drill hole cores revealed dark-gray graphite-quartz-sericite-penninite schists with the following minor constituents: albite, muscovite, greenish biotite, fragments of tourmaline, large leucoxene grains up to 0.43 to 0.85 millimeters, plates of penninite, ilmenite, ilmenorutile, and rutile in prismatic crystals, partly leucoxenized. In the chlorite-quartz interbeds the quartz is tightly intergrown with the sericite-chlorite groundmass. Titanium minerals (which in places are smoothed out) and penninite are mostly parallel to the bedding. Under high magnification the leucoxene shows parallel extinction, but some grains of similar shape are only slightly or not at all transparent.

The grains of leucoxene are highly porous; the pores are either isolated or interconnected. These pores are filled with quartz, and more rarely with mica. The specific gravity of this leucoxene[2] is 3.20 to 3.30. Black rutile grains (specific gravity exceeding 4.05) in reflected light reveal a high index of refraction and have typical lustrous white crystal surfaces. X-ray analysis of the titanium minerals (both the black elongated prismatic unaltered grains and the gray leucoxenized grains) in both cases showed distances between parallel planes characteristic of ilmenorutile, rutile, and quartz (evidently ingrowing crystals), and only in few cases did these distances correspond to those of ilmenite. The ilmenorutile is an alteration product of ilmenite (?). Data on the chemical composition of the schists (Table 2) show that MgO:CaO, K_2O:Na_2O are predominant in molecular quantity. This also attests to the sedimentary origin of the schists. Part of the Na_2O content, however, is evidently introduced from magma, since quartz-feldspar veinlets are found in the schists. The F, which is uniformly distributed throughout the schists, is apparently of sedimentary origin. In the interstitial water circulating in the schists the strontium content reaches 60-130 mg/l, and the bromine content 224 mg/l. The total titanium-dioxide content of the schists in the Yarega River area averages 0.77%, and that in the Ukhta area averages 0.70%. In Zhivetsky basal

[2] **The description of this leucoxene by D. P. Serdyuchenko [11], and his conclusion that the leucoxene was formed after the sphene which is widely distributed in the schists of the Southern Timan, are erroneous.**

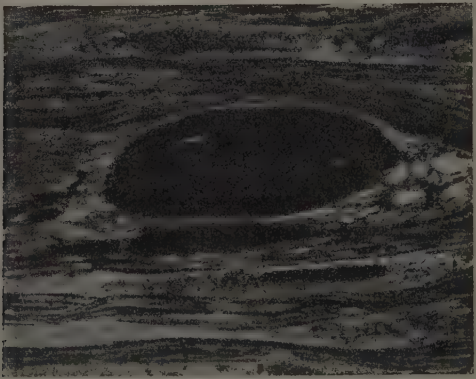

FIGURE 4. Quartz-chlorite-sericite-mica schist, muscovitized and enriched with prismatic leucoxene and rutile. Lepidoblastic, blastoporphyritic textures showing traces of plication and dragging of the grains (the Ukhta area, Southern Timan).

Magnification 160X.

sandstone of this area, overlying the Bobrovaya formation, concentrations of leucoxene and rutile were found associated with gravelly layers; here the titanium-dioxide content increases to 15% or more and the content of rare elements is as follows: Nb_2O_5 to 0.06%, Ta_2O_5 to 0.02%. The increase in the amount of rare elements is due to the presence of columbite. The composition of the heavy mineral residue is leucoxene, 45 to 90%; zircon, 0.4 to 14%; monazite, to 1%, xenotime, to 0.05%. In the Pashiysky strata of the Lower Frasnian substage some packs of sandstones are also enriched in leucoxene (up to 73% of the rock's weight).

In the Southern Timan granites are found north of the V-shaped bend of the Ukhta River, in the Chut' River basin, under unmetamorphosed clays of Givetian age. These clays contain two micas, are rich in rare earths and other minerals, and have an active contact with the schists of the Bobrovaya formation, which are here altered to quartz-plagioclase-biotite hornfels mineralized by radioactive and other minerals [7].

In addition to the central zone, in the Southern Timan (Fig. 1), ancient rocks were discovered under sedimentary deposits by drill holes in the territory of the Eastern Timan (in the areas of the Ayyuva, Nyamed, Lek-Kem, Sedël', Izkos'gora, Voy-Vozh, Nibel', Perevolok, Nyumylga, Zelenets, and Ezhvador Rivers). In places the drill holes revealed a weathered crust on the ancient rocks and intruded granitoid rocks. The drill holes in all the above localities penetrated only some 10 to 50 meters of ancient rocks. This makes it difficult to identify the schists and quartzitic sandstones encountered in individual drill holes, especially because the identifying dolomites of the Bystrukha formation are absent and the schists show various modes of dislocation: in places they are almost horizontal (dip 5°), but they are almost vertical (65° to 75°) elsewhere. In most of the localities the drill holes penetrated rocks common in the Timan area: dark-gray and ash-gray schists and sandstones, in texture and composition resembling the schists of the Bobrovaya formation exposed at Och-Parma, containing powdery and grainy leucoxene, fine-scaly chlorite and particles of penninite. But some of the drill holes in the Nyamed' structure penetrated schists containing discrete grains of rounded leucoxene. Quartzitic sandstones were discovered by several drill holes at Sedël, Izkos'gora, and Nibel'. According to composition, the following varieties of these sandstones have been distinguished: quartz sandstones, infiltration-ferruginous sandstones, mica-quartz sandstones, siderite-chlorite-quartz sandstones and sericite-chlorite quartz sandstones. The titanium-dioxide content of the schists is as follows: at Ezhvador 1.23%, at Zelenets 0.77%, at Nyamed" 0.09%, and at Sedël 0.18%. Spectrographic analysis shows that in regard to copper content and the absence of strontium, the Ezhvador schists (Table 1) are closer to the schists of the Chetlass formation at Och-Parma. The chemical composition of the unaltered schists (Table 2) is characterized by a relatively low aluminum-oxide content, ranging from 12.58% to 14.78% (Zelenets, Nyamed, and Sedël').

The weathered crust on the schists has been preserved in some depressions of the Verkhne-Izhem area. The upper part of this crust is composed of reddish-brown quartz-hematite-sericite schist altered to hematite, or of quartz-hematite-sericite schist containing kaolinite; their thickness reaches 20 to 30 meters (Voy-Vozh, Sedël', Kush-Kodzh, and elsewhere). Iron oxides impregnate the schists (by infiltration) or are disseminated as individual grains of iron monohydrate. Chlorite is in places entirely discolored. At Kush-Kodzh the ferruginous schists are replaced downward, along the fissures, by kaolinite; siderite grains are attached to the walls of the fissures. In some places the rock grades into kaolinized schists containing disseminated sericite flakes and grains of quartz and siderite. At Zelenets a weathered crust composed of kaolinite has been preserved, containing grains of quartz, sericite and siderite, the latter having irregular shapes; this grades downward into ash-gray and dark-gray schists. Table 2 gives the chemical composition of the schists in the weathered crust.

Of great interest are the fragments of tracheids with rimmed pores, and other remains of higher plants, found in the ash-gray quartz-sericite-chlorite schists at Ezhvador (Fig. 5, 1 - 5). Individual spores were also observed in cores from Och-Parma, Zelenets and Voy-Vozh, as well as in the schists of the Yarega River area (Fig. 5, 6 - 12). These findings indicate either that the higher plants are extremely ancient, or that organic remains are readily introduced into ancient rocks by circulating waters. Thus age determinations of ancient rocks on the basis of spore-pollen complexes must be made with great caution. Such determinations are possible, however, and provide great possibilities for dating the gaps in stratigraphic records. Unfortunately the plant remains found in the area under investigation here cannot thus far contribute to the solution of the question of the age of the ancient rocks.

In the Eastern Timan region intrusive rocks pierce the schists [7]. In the Izkos'gora area these are represented by quartz syenites and quartz monzonites; in the Nizhnaya Omra area there occur granites of normal composition,

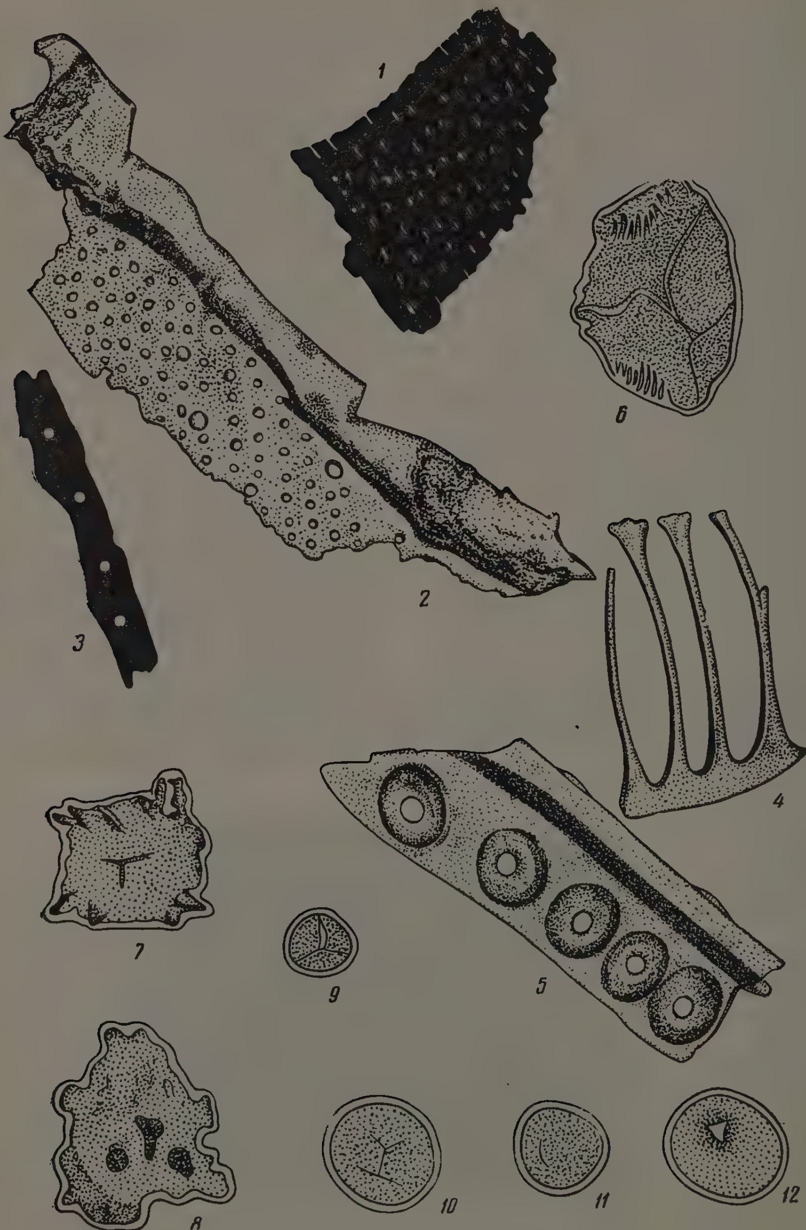

FIGURE 5. Plant remains in schists, bore-hole No. 1, the Ezhvador area.

1 and 3 -- pitch-black plant remains, reticulated, magnification 200X; 2, 4, and 5 -- fragments of tracheids' plates, brownish-yellow in color with bordered and scalairform pores, magnification 600X; 6 to 12 -- spore remains, magnification 400X, bore-hole No. 1m, Yarega area.

containing two micas.

The effect of the granite intrusions on the enclosing schists is best seen in the cores of drill holes in the Chut' River basin. Here the schists of the Bobrovaya formation have been altered to hornfels. The following hornfels varieties were observed: quartz-biotite-tourmaline, biotitized, quartzitic and albitized hornfels. The following minerals are typical: quartz, biotite, albite, oligoclase, muscovite, tourmaline, zircon, rutile, chlorite, penninite, apatite, malacone, sericite, leucoxene, ilmenite, actinolite, a radioactive mineral that is isotropic and shiny white in unpolarized light, and secondary titanite. Biotite occurs in wide brown plates and shows abundant pleochroic halos of two or more concentric circles. The schists have a porphyroblastic texture in a fine-grained groundmass. The metamorphic rocks in the Ukhta and Chut' sections are characterized by a higher degree of metamorphism than the Och-Parma schists. This is indicated by their quartzitization, biotitization, felspathization and zirconization, as well as by the occurrence of radioactive minerals in the biotite and of quartz and quartz-feldspar veinlets containing sulfide ores of lead, zinc, and copper. In the Ayyuva area (drill hole No. 2) there are thick-plated quartz-sericite-chlorite schists containing penninite particles and revealing no traces of contact metamorphism.

The ancient rocks of the Central Timan have already been described by F.N. Chernyshev [14]. E.A. Kal'berg [16], who did the geologic mapping of Chetlasskiy Kamen' Hill in the 1940's, was the first to subdivide these rocks into formations; she distinguished the following formations (from bottom to top): the Chetlass, the An'yugskaya (the analogue of the Dzhezhim formation) and the Bystrinskaya (analogous to the beds of conchoidal dolomites at Dzhezhim-Parma and Och-Parma). E.A. Kal'berg stressed the existence of a gap and an unconformity between the Chetlass and the overlying An'yugskaya formations. She collected organic remains from the calcareous-dolomitic beds of the Bystrinskaya formation, which were identified by A.G. Vologdin [5] as Solenopora, Girvanella and Collenia, suggesting that these beds belong to the Middle Cambrian. Later, on the basis of extensive geologic surveys (1946-1950), the geologists of the Ukhta Combine made a more detailed stratigraphic subdivision of the ancient rocks in this area. They combined the upper part of the Dzhezhim formation, consisting of schists, and the lower part of the Bystrinskaya formation into the separate Bobrovaya formation. The remaining calcareous beds, which grade upward into silty shales, they distinguished as the Bystrukha formation (after the Bystrukha River).

Schists of the Chetlass formation crop out in the core of the Chetlass anticline, along the Nizhnyaya Puzla, Verkhnyaya Puzla, Vizinga, and Kos'yu Rivers. In places the dip is as much as 45° to 80°. The formation is composed of homogenous thick-bedded schists, brownish-yellow and greenish in color. There are sandy interbeds 1.0 to 1.5 centimeters thick; in some places these soon wedge out along the strike, but in other places they become thicker and the schists acquire a beaded texture. These schists have a secondary schistosity, which is almost always perpendicular to the primary schistosity. The schists have the following mineral assemblages: quartz-sericite-mica and quartz-biotite-chlorite-sericite-mica. The interbedded quartzites are composed of chlorite, sericite and quartz. All the varieties of schists have undergone various degrees of quartzitization, albitization and biotitization and contain a graphite-like substance.

The Dzhezhim formation is widely distributed throughout the Central Timan. It forms the core of the Chetlass anticline, exposed on the valley slopes of the Mezen', Kos'yu, Verkhnyaya Puzla, Nizhnyaya Puzla, Vizinga and Chetlass Rivers. It is also observed in the talus of the watersheds of the Mezen' and Myla River basins where it forms the core of the eastern flank of the fold, complicated by longitudinal faults. On the watersheds adjoining the Rochuga and Korennaya Rivers, the Dzhezhim, Bobrovaya and Bystrukha formations form a syncline. The Dzhezhim formation is composed of more or less uniform, thick-bedded medium-grained quartzitic sandstones and quartzites. Cross-bedding is observed in places. There are layers of schists some 1 to 3 meters thick. Some varieties of quartzitic sandstones are brownish-red or pink in color, resulting from the decomposition of pyrite. Near the schist outcrops of the Chetlass formation (along the Vizinga, Puzla, and other rivers), there are fragments of conglomerates containing schist pebbles. On the Svetlinsky Golets large pebbles of schists, with a schistose texture, are found; these resemble the schists of the Chetlass formation. Quartz is the main constituent of the sandstones. The associated minerals are sericite, mica, feldspar and pyrite, the latter two less abundant.

The Bobrovaya formation is observed on the flanks of the Chetlass anticline and in several places along the Verkhnyaya Senka, Tsil'ma and other rivers. In the area of the Bobrovaya River, the exploratory drill holes have shown how the sandstones of the Dzhezhim formation grade into the schists of the Bobrovaya formation. These schists usually show an interbedding of schist layers (originally clays) and siltstone quartzites (originally siltstones). Beds of quartzitic sandstones up to 3 meters

thick are less important, and occur only in the middle part of the formation. On the upper reaches of the Gnilaya River, the Bobrovaya formation is hidden by the overlying rocks of the Bystrukha formation. The schists exposed along the Umba and Srednyaya Rivers and on the upper reaches of the Vym' River probably belong to the Bobrovaya formation.

On the Chetlasskiy Kamen' the Bobrovaya formation is composed of gray and dark-gray schists, which are almost black in the top part of the formation. They are thick-bedded, platy and form packs. Individual plates are as much as 1.5 centimeters thick. These schists contain 40-50% quartz, 20-30% sericite and 15-20% of thin chlorite flakes. In the Bobrovaya River basin, in the schists and especially in the quartzite layers, there is a series of thin quartz and feldspar-quartz stockwork veinlets, with hematite, ilmenorutile and ferritorite ore minerals. In some quartz veins up to 30 to 60 centimeters thick, tabular columbite and zircon were found, and in others galena, ferritorite, limonite, etc. The schists exposed on the upper reaches of the Bobrovaya and Kos'yu Rivers contain biotite, aegirite and feldspar, as well as feldspar-aegirite and feldspar-aegirite-arfvedsonite-augite veinlets; these factors indicate the presence of rocks associated with alkaline magma in the depths. Quartz-microcline-muscovite vins occur occasionally in the basin of the Bobrovaya River. The microcline usually contains many disseminated microcrystals of rutile and muscovite; this saturation of microcline by rutile is evidence of the introduction of titanium into the magmatic phase. The alteration of the schists at the contact with the above veins takes the form of a muscovite border of the greisen type, 5 to 7 centimeters thick. In the groundmass, consisting of fine flakes of mica, the following minor constituents have a random orientation: rutile in elongated prismatic crystals 0.43 x 0.09 meter in size, smaller microlitic crystals and also remains of quartz and microcline with a characteristic lattice. The brecciated quartz sandstones are in places cemented by microcline containing zircon, rare radioactive minerals and tourmaline. In the basin of the Mesen' River ferritorite was also found in quartz veins intersecting the schists.

In the schists of the Bobrovaya formation interbeds of schists (formerly clay), consisting of quartz-chlorite-sericite schists, graphitized and containing prismatic leucoxene (after ilmenite, rutile and ilmenorutile), apatite, allothigenic zircon and tourmaline, alternate with sericite-muscovite-quartz schists of small thickness (initially siltstones). These schists (Fig. 7) are identical to to schists of the Bobrovaya formation in the Ukhta area (Fig. 4). Titanium minerals are mainly associated with the chlorite-mica layers, which in places contain pyrite. Some leucoxene grains recrystallize along the edges into rutile. In certain varieties of schists sericite is the chief constituent and chlorite is subordinate. In the Chetlass area the schists of the Bobrovaya formation are enriched in allothigenous fine tourmaline. The tourmaline grains in the heavy-mineral residue are elongated, angular, sometimes subrounded. Pleochroism ranges from light green (β) to colorless (ω). Bands around the prism or its termination are pleochroic, ranging from light brown (β) to colorless (ω). Spherical, rounded tourmaline grains show pleochroism from intensive-green or brown (β) to almost or entirely colorless (ω). Accumulations of elongated tourmaline grains are associated with very thin chlorite-mica laminae. The grains usually show a linear orientation in the same direction, lying in rows and in chains, sometimes with interruptions. In an area of 0.6 x 0.17 millimeters there are up to 13 tourmaline grains which do not show any predominant association either with the graphitized bands or with bands (mostly of chlorite-mica composition) containing grains of prismatic leucoxene and ilmenite. In places microlitic tourmaline needles are associated with graphitized sericite-chlorite bands; these microlites do not show any clear linear orientation, and they may possibly have originated in the metamorphism of the schists.

Light bands and small lenses of quartzitic siltstone range in thickness from fractions of a millimeter to 4 mm. They differ sharply from the above-described bands, since they are composed predominantly of quartz grains, sericite, rare grains of leucoxene, rounded zircon, and fragments of tourmaline.

In papers on sedimentary-metamorphic rocks little attention has been paid to analysis of the forms of tourmaline and its position in the groundmass. The present author has for many years studied the clays and sandstones of the Timan sedimentary mantle. These studies show that "fresh" grains of tourmaline are abundant in the sedimentary rocks of the Timan. Sometimes the tourmaline content reaches tenths of a per cent of the heavy-mineral residue. The tourmaline grains are genetically associated with the decomposition of the metamorphic rocks.[3]

The bands of schists and silty sandstones in the middle part of the Bobrovaya formation are best studied in the Bobrovaya River area,

[3] D.P. Serdyuchenko [11] believes that the appearance of tourmaline in the Timan schists is associated with the boron concentration in sandy-clay marine and lagoonal ancient deposits; this statement is one-sided, influenced by his own ideas and ignores other sources.

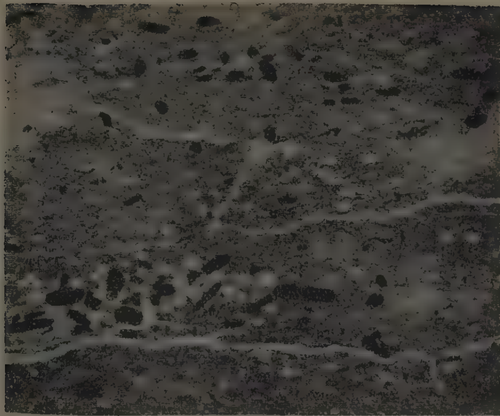

FIGURE 6. Quartz-chlorite-sericite schist with interbeds of rutile-quartz sandstones (Bobrovaya River Basin). Magnification 60X.

where they have been revealed by numerous exploratory drill holes. The chief constituents of the sandstones are quartz and subrounded rutile. The latter also occur in the sandy schists (Fig. 6), whose groundmass is composed of chlorite and sericite; here the associates are clastic leucoxene (after small subrounded crystals of rutile), zircon and tourmaline. The latter shows pleochroism: brown and light-brown with respect to β and mostly colorless with respect to ω. Bands around the tourmaline prisms show blue (β) and colorless (ω) pleochroism. The zircon is colorless. Tables 1 and 2 show the results of chemical and spectrographic analyses.

Along the Umba River, thick-bedded schists with the following mineral assemblages are exposed: graphite-sericite-chlorite-quartz, with prismatic leucoxene and a lepidoblastic

FIGURE 7. Epidote-sericite-chlorite schist (gneiss-phyllites), enriched with prismatic leucoxene (after rutile and ilmenorutile). Lepidoblastic texture with traces of plication and dragging. (Korennaya River, Middle Timan). Magnification 160X.

texture; some varieties occur in bands. Minor minerals are pyrite, muscovite plates, zircon and tourmaline grains, chlorite and penninite plates. The latter is associated with graphitized areas; the leucoxene grains contain quartz growths. Discrete pleochroic halos are observed in the penninite. Schists with a similar composition are exposed on the upper reaches of the Srednyaya and Vym' Rivers.

Exposures along the Tsil'ma River are made up of dark-gray hard schists of the Bobrovaya formation, whose mineral assemblage is epidote-sericite-chlorite; leucoxenized ilmenite and prismatic rutile crystals (Fig. 6), acidic plagioclase and biotite are the accessories, while apatite, muscovite and relicts of basic plagioclase (epidotized) occur more rarely. The schists have a lepidoblastic texture with some plication. The total content of TiO_2 in the Bobrovaya formation in the Bobrovaya River basin averages 1.08% (determined from 4 samples), thus exceeding the TiO_2 content in the schists of the Ukhta area.

The Bystrukha formation, 2,500 to 3,000 meters thick, caps the Pizhma-Svetlinskaya plain. Along the Gnilaya River the contact between the schists of the Bobrovaya formation and the overlying dolomites of the Bystrukha formation may be observed. Its basal part is composed of dolomitic marls interlayered with shales and grading into conchoidal calcitic dolomites and in places into algal, horizontally laminated and marbleized limestones. Brecciated limestones up to 100 meters thick are found along the right tributaries of the Rochuga River and elsewhere. The upper part of the formation is composed of the gray fine-plated slates distinguished as the whetstone subformation.

In the Chetlass area igneous intrusions penetrate the schists of the Bobrovaya formation. Diabases are exposed along the Kos'yu River; these are greenish-gray, in places amygdaloidal, represented by two varieties. The first is amphibolitized diabase composed of labradorite (from seriticized to fresh), augite, and secondary biotite, amphibole, chlorite, and quartz; the accessory minerals are ilmenite, apatite, magnetite, leucoxene after ilmenite and the rock has an ophitic texture. The second is a highly saussuritized labradorite-pyroxene diabase containing chlorite.

Syenites occur in the area of the Kos'yu and Bobrovaya Rivers. There are three kinds: a) a light pink aegirite-orthoclase-biotite syenite containing apatite and titatite; and b) a pinkish-gray aegirite-orthoclase-arfvedsonite syenite showing traces of cataclasis. The orthoclase is in places perthitized; the arfvedsonite is often split and twisted; the aegirite occurs in stellate aggregates or elongated prisms; the orthoclase shows poikilitic growths of hornblende which is sometimes replaced by aegirite; and goethite fills the spaces between the grains. The third variety c) is aegirite-arfvedsonite-orthoclase-augite melanocratic coarse-grained syenite. This is in places intensively carbonatized and grades into a carbonatite rock occasionally containing hydrogoethite. The carbonate is as much as 61% to 100% by weight. Barkevikite, No. 49 plagioclase and vermiculite mica have been observed in this rock. γ of the pyroxene ranges from 22° to 44°, and there is almost no pleochroism. The carbonates are represented by dolomite, rhodochrosite and other minerals. The dolomite contains remains of orthoclase and hornblende, along with hydrogoethite inclusions. The hydrochloric-acid extract contains 4.15-14.12% of Fe_2O_3, 3.98-11.27% of MgO, 7.4-9.09% of CaO and 0.45-1.25% of MnO.

The carbonatization is associated with the latest phase of hydrothermal alteration. Granites have not yet been found in the Central Timan, but their presence is supposed. In the Kos'yu River area exploratory drilling has revealed breccia zones up to 3 meters thick in the schists. Ore minerals are hydrogoethite, goethite and limonite; pink feldspar occurs as corroded crystals. The iron content is about 43% and the manganese content up to 1.7%.

The Northern Timan has a wide distribution of pre-Silurian dark-gray thin-banded quartz-sericite and biotite schists. These were described by F.N. Chernyshev [14], who found that they are overlain by limestones containing Upper Silurian brachiopods. These ancient schists have been known since 1935 as the Barmin formation, a number of kilometers thick. The stratigraphic position of these schists is the same as that of the Chetlass formation in the Southern Timan, so that the two formations are apparently analogous. The schists are exposed in the coastal area of Cheshskaya Bay, Cape Barmin, Cape Severniy Rumyanichnyy, at Malyy and Bol'shoy Kameshek, along the Vas'kina and Kombal'nitsa Rivers and in several other localities. The formation is intensively folded, forming steep isoclinal folds, partly broken, with the flanks dipping 60°-85°. The strike of the schists is NW-SE, 305° to 345°, deflecting to NE 20°. At the Cape Severnyy Rumyanichnyy, the schists dip eastward 75°. These schists are gray and dark-gray in color, sometimes greenish, and are composed of sericite, quartz, and biotite. Muscovite is less abundant, and No. 8 plagioclase and graphite occur in places. The schists are biotitized at the contact with quartz syenites (Malyy Kameshek).

Neither the Dzhezhim formation nor its analogue has yet been discovered here in the bedrock. A.A. Chernov [13], however, has

noted the occurrence in this area of quartzite pebbles in Devonian basal conglomerates and sandstones. The sandstones of the Dzhezhim formation are apparently concealed under younger beds.

The schists of the Bobrovaya formation have not yet been recorded in the Northern Timan. Regarding the conchoidal dolomites of the Bystrukha formation, F.N. Chernyshev noted that he saw these in the Cheshskaya Bay area, but did not distinguish them as a formation.

Intrusive rocks are found in several localities of the Northern Timan and are represented by various types. At Cape Barmin, among the schists, there are veins of modified gabbro-diabase, which according to D.S. Belyankin [1] are probably genetically associated with both alkaline rocks (shown by the presence of barkevikite) and granites (shown by the presence of biotite and albitic micropegmatite). At Malyy Kameshek gray and red syenites occur among the schists [7]; they are intersected by pegmatite-aplite veins 1.5 to 3 meters thick and composed of albite and microcline, with an admixture of muscovite and quartz. This author was first to find ferritorite among the accessory minerals in the Timan, in the form of small grayish-brown prisms containing up to 8-11% of Fe_2O_3, fluorite, apatite, zircon, mackintoshite and pitch-black ore minerals of the columbite type. Quartz veins 0.30 meter thick were found in the schists.

At Cape Severnyy Rumyanichnyy, the schists are intersected by veins of: 1) augite-porphyrite, 2) gneissic aegirite-nepheline syenites and 3) essexite. The pegmatites contain pockets of galena and sporadical ferritorite, as well as veins with molybdenite and fluorite. At Bol'shoy Kameshek there are exposures of gray granite containing two micas (mostly biotite), in contact with biotite schists.

Table 3 shows a correlation of the ancient formations in several areas of the Timan. This clearly shows the continuity of all the ancient beds in areas which underwent comparatively small uplift. In areas of more intensive uplift (the Northern Timan, the Chetlasskiy Kamen' Hill and the Ukhta area), the older rocks are exposed in the cores of structures; the Bobrovaya and Bystrukha formations are partly or completely eroded.

CONCLUSIONS

The metamorphic rocks of the Timan basement reveal two cycles of sedimentation and two phases of folding, accompanied by magmatic intrusions. The lower, or Chetlass, formation is associated with the first cycle. After deposition, it was involved in intensive orogenic movements. The gabbro and nepheline-syenite intrusions in the Northern Timan are probably associated with the Chetlass phase of folding [6].

The Dzhezhim formation, containing basal conglomerates with schist pebbles of the Chetlass formation, marks the beginning of the second cycle of sedimentation. The rocks of the Dzhezhim, Bobrovaya and Bystrukha formations form a single transgressive complex, characterized by successive grading of formations into each other. At the end of Bystrukha time the second, or Timan, phase of folding took place, accompanied by the intrusion of granitic and syenitic magmas. Quartz veins with iron sulfides have thus far been known in the Bystrukha formation.

The geologic age of the ancient rocks has not yet been determined. It is doubtful that the stromatolite remains were identified correctly, and the results of spore-pollen analyses of these rocks are not reliable. The occurrence of tracheids with rimmed pores must be verified. The metamorphic rocks are undoubtedly of pre-Silurian age, since they are unconformably overlain by Silurian limestones; this does not exclude the possibility of their being Riphaean in age.

The transformation of the deposits into sedimentary-metamorphic rocks was due to orogenic movements and magmatic intrusions. The degree of effect of these factors, the nature and abundance of the solutions and sublimates and the primary composition of the sedimentary rocks determine the distribution of metamorphic zones characterized by various degrees of alteration of the rocks.

The mineral indicators of a high degree of metamorphism are zircon, apatite, feldspar, aegirite, biotite, albite, muscovite, ilmenite, rutile and tourmaline (the last encountered in the hornfels exposed at Verkhnyaya Chut'). In chemical composition the schists are characterized by a low content of aluminum oxides and a relatively high content of SiO_2 and alkalis (Table 2). A similar proportion of rockforming elements in the initial deposits, and the presence of Fe, Mg and Ti, favored the reactions leading to the formation of feldspar, light and dark mica, chlorite, ilmenite and rutile (in some zones in the schists). This composition excludes the formation of new minerals rich in aluminum oxides. In the sedimentary rocks (Table 2), the beds of clay formed through the decomposition of schists are highly enriched in aluminum oxides and have a markedly low SiO_2 and alkali content. Under the conditions of the metamorphism, new minerals and mineral

Table 3

Correlation of stratigraphic sections of metamorphic rocks in several areas of the Timan

Southern Timan			Middle Timan	Northern Timan
Dzhezhim-Parma	Och-Parma	Ukhta area (data obtained from drill holes)	Chetlasskiy Kamen'	Cape Barmin, Cape Servernyy Rumyanichnyy, Malyy Kameshek
1. Bystrukha formation. Calcitic algal dolomites, conchoidal, thin- and thick-bedded, (Collenia and Conophyton). At top and bottom occur fresh interbeds of marl and argillites. Thickness 1,000 meters.	1. Bystrukha formation. Calcitic dolomites, usually gray and dark-gray in color, conchoidal algal (Collenia and others). Thickness 2,000 to 3,000 meters.	1. Bystrukha formation eroded.	1. Bystrukha formation. At the bottom calcitic dolomites, conchoidal, with algae Solenopora timanica, Girranella, and others. At the top sericite-mica slates (whetstone subformation). Thickness 2,500 to 3,000 meters.	1. Bystrukha formation eroded.
2. Bobrovaya formation: aluerite-sericite-mica schists, interbedded with quartz-mica aleurolites, with beds of arkoses. Thickness 1,350 meters.	2. Bobrovaya formation: thin-plated schists, dark-gray and gray. Thickness 2,500 meters.	2. Bobrovaya formation, in places eroded. Schists gray and dark-gray, thin-banded, sometimes plicated, in places dense, quartzitic.	2. Bobrovaya formation. At the bottom — schists, thin-banded, gray; in the middle, interbeds of quartzitic sandstones with thickness up to 20 meters. At the top — schists, gray, thin-banded. Thickness 1,000 to 2,000 m.	2. Bobrovaya formation eroded (?).
3. Dzhezhim formation. Sandstones, gray and pink, interbeds of conglomerates. Thickness 760 meters.	3. Dzhezhim formation. Sandstones, dense, gray and pink, quartzitic, thickness 200 to 300 meters.	3. Dzhezhim formation. Quartzitic sandstones, gray, composed of quartz, underlain by conglomeratic sandstones with pebbles of schists. Thickness 260 m.	3. Dzhezhim formation. Thick-plated quartzitic sandstones, in places cross-bedded, interlayered with schists. Thickness 250 to 300 meters.	3. Dzhizhem formation eroded.
4. Chetlass formation. Shales, black-gray.	4. Chetlass formation. Schists, dark-gray, thick-bedded, interbedded with dense siltstones, in places quartzitic.	4. Chetlass formation. Schists, dark-gray, thin-plated, plicated.	4. Chetlass formation. Schists, thick-bedded, dark-gray, brownish-yellow and green in color.	4. Chetlass formation. Schists gray and dark-gray, dense, quartzitic, thick-bedded, in places plicated, steeply dipping.

associations different from the mineral assemblages of the schists may appear.

Alkali metasomatism in the schists is manifested in the formation of muscovite in greisens and of sericite, muscovite and albite in the schists and hornfelses, and in the microclinization of ore-bearing breccias containing zircon and ferritorite. The formation of biotite in some places probably results from the interaction of chlorite and sericite molecules. The fact that elements Ta, Ce, La, Di, Y, Nb, Zr, Th, P, K, Na, B, OH, and Ti were introduced from the magma is shown by the presence in the quartz-biotite hornfelses, of monazite, zircon, malacone, apatite, columbite and tourmaline associated with biotite, as well as by the presence in the breccias of zircon, rutile and ferritorite. There are some residual ilmenite and rutile grains in the Timan schists, as well as grains of these minerals formed as a result of metamorphism. The latter was apparently associated with the movement of titanium and iron, contained as a physical admixture and as products of the decomposition of other minerals in primary sediments which underwent deep contact and dynamic metamorphism. Ilmenite- and rutile-bearing schists are found in some areas of the Timan, forming an ilmenite-rutile-leucoxene province. These schists are the source of the accumulation of placers of titanium and other ores in the sedimentary mantle, representing a new type of sedimentary-metamorphic (primarily argillaceous) rocks. This type was not previously considered in genetic classifications of titanium-ore deposits [9].

The presence of a weathered crust on the schists is not only of scientific interest, but also of very great economic importance as a leading indicator in the search for enriched zircon-titanium and other placers and for sedimentary bauxite and iron ores associated with the sedimentary mantle of the Timan. This statement has been confirmed by the recent findings of the present author, who has discovered in the Timan: 1) a deposit of ilmenite-rutile-leucoxene overs; 2) the presence of 2-to-3-meter thick layers of oolitic ironstone in sediments of Givetian age; 3) bauxite and iron-ore layers in Lower Carboniferous rocks. The geologic conditions in the Timan indicate that this region has prospects of containing endogenic mineral deposits, particularly of rare elements, associated with alkaline syenites and iron carbonates; a search for these deposits should be made in the zones of fractured schists.

The above data on the composition of the sedimentary-metamorphic rocks in the Timan, on the development of the weathered crust and on the enrichment of the Southern Timan sedimentary mantle in aluminum oxides, iron and titanium, may be of interest in correlating the ancient rocks of the basement and the sedimentary beds of the Russian platform, as well as in evaluating their ore-bearing possibilities. These data also enable us to see significant differences between the sections of ancient rocks of the Timan and those of the ancient metamorphic rocks of the Urals, dated as Riphaean.

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THE AGE RELATIONSHIPS OF IGNEOUS DIKES AND POST-MAGMATIC MINERALIZATION IN THE DEPOSITS OF NORTHERN KIRGHIZIA[1]

by

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PRELIMINARY REMARKS

The age relationships of igneous dikes and post-magmatic mineralization are one of the most controversial and long-discussed problems both in petrography and in the study of ore minerals.

The main difference of opinion on this problem consists of the following: are there or are there not post-ore or intra-ore dikes among the products of a magmatic phase taken by itself, including the magmatic processes? Some investigators (V. M. Kreyter, A. V. Pek, F. I. Vol'fson, L. I. Lukin, A. V. Korolev, V. E. Poyarkov, the author of the present article and others) believe that such dikes do not exist. All dikes, regardless of their composition and the time of their detachment from the originating magma chamber, are pre-ore in regard to the post-magmatic, especially hydrothermal mineralization which initiated in the same chamber. Other investigators (Kh. M. Abdullayev, Ye. A. Radkevich, F. K. Shipulin, M. A. Favorskaya, V. N. Kotlyar and others) believe that in each magmatic phase there can be pre-ore, intra-ore and post-ore dikes of igneous rock. And although this problem has been discussed for a long time, the advocates of each view have thus far not been able to come to agreement. It is of importance, moreover, that all investigators acknowledge the great and practical, as well as theoretical significance of this problem, since its solution will throw light not only on certain aspects of petrology and ore-genesis, but will also in important ways facilitate the discovery of prospecting criteria for a number of extremely valuable mineral deposits. It is typical that the most thoroughgoing consideration of the age relationships of dikes and mineralizations on a high theoretical level has been made in the Soviet Union. And in spite of the contradiction of views on this problem, each argument and each quoted fact is without any doubt valuable and brings us closer to an objective solution of the problem as a whole.

At the present time in the territory of Northern Kirghizia one may sufficiently clearly distinguish the products of at least three ore-bearing phases of igneous activity. Each phase includes the formation of massifs of different igneous rocks, of varying vein complexes and various post-magmatic ore occurrences. The earliest phase took place in the early Paleozoic, but its age cannot at the present time be more precisely determined. It has been established that the lower age boundary of this phase is the top of the Upper Silurian, and that the upper boundary, at least in the opinion of certain investigators, is the lower Carboniferous. The majority of Kirghizian geologists are inclined to the opinion that the most active period of this phase most likely belongs to the Lower or Middle Devonian. The granite differentiation product is the ore-bearing one in this phase.

The following phase, in the opinion of a number of investigators, occurs in the late Carboniferous and the last phase, finally, in the Permian (in the upper Permian). Thus far it is again impossible to determine the age more precisely. In the last phase, the ore-bearing components were the somewhat earlier alaskite differentiation product and the alkaline differentiation product, which was evidently somewhat later.

The post-magmatic phenomena of each phase are characterized by specific features of their material composition and by certain other characteristics. All this has been set forth in greater detail in another article by the present author [15].

THE AGE RELATIONSHIPS OF THE DIKE ROCKS

The Granitnaya Gorka deposit belongs to the most ancient, tentatively Devonian metallogenic phase. According to G. P. Lyubogo-

[1] Vozrastnyye sootnosheniya dayek izverzhennykh porod i postmagmaticheskogo orudeneniya na mestorozhdeniyakh severnoy Kirgizii.

shchinskaya (1957), the lead mineralization is here associated with a zone of tectonic dislocations in Caledonian granitoids. This same zone contains dikes of andesite porphyrites, which apparently belong to the same tentatively Devonian magmatic phase.

Macroscopic observations by themselves solve the problem of the age relationships of the porphyrite dikes and the mineralization in favor of the pre-ore age of the prophyrites. The dikes are intersected by ore veins both along their trend and across it. Moreover both the granitoids and the porphyrites within this tectonic zone have undergone intensive alteration about the ores, reflected in the sericitization and the carbonatization of the granitoids and the chloritization, sericitization and carbonatization of the porphyrites.

A study of the mineral composition of the heavy fraction of pulverized specimens from the macroscopically least altered parts of the dikes has revealed a fairly well-developed complex of secondary minerals, whose composition is similar to that of the ore bodies: galena, pyrite, sphalerite, bornite, quartz, carbonates, etc. This fact also indicates the pre-ore age of the porphyrites.

From the example of the Granitnaya Gorka deposit it is thus easy to establish the simplest case of the relationship between the dike formations and the mineralization. The same simple relationships, testifying to the pre-ore age of the dikes, may be traced in the deposits of Ak-Tash-Koro, Taldy-Bulak and many others.

The Aksuy group of deposits also belongs to the tentatively Devonian metallogenic phase. Along with a number of deposits, the region contains a well developed variety of vein rocks of the same magmatic-metallogenic and kersantites. The pre-ore age of all the vein formations, with the exception of the lamprophyres, is clear beyong any doubt. The age relationships between the lamprophyres and the ore mineralization are a somewhat more complicated question. Many investigators, guided only by their visual observations, have considered them to be post-ore in age. It is true that macroscopic observations would seem to confirm this conclusion, since the dikes externally intersect the ore bodies, but this is merely an illusion.

The age relationships of the lamprophyres and the ore mineralization have been discussed in fairly great detail by I.K. Davletov [6]. In solving this problem I.K. Davletov used various methods: a detailed study of the contacts and the alterations of the dikes within and outside the ore bodies, of the accessory minerals, etc. As a result of his investigations he came to the conclusion that the lamprophyres were earlier than the ore. He offers the following proof.

1. All the lamprophyre dikes within the "intersected" ore bodies are intensively altered: they are leached, chloriticized, sericiticized, carbonatizised, and altered to quartz. Within the contact zone they frequently lose their primary structure and are transformed into a complex fine-aggregate mass of innumerable components. In the central parts of the dike, however, the outlines of the individual mineral units are still preserved. The alteration of the lamprophyres is similar to the hydrothermal metamorphism around the ores within the other enclosing rock. The alteration decreases sharply as the dikes emerge from the ore body, and at a comparatively small distance from the latter, the lamprophyre dike bears almost no traces of alteration.

2. The content, within the lamprophyres, of primary accessory minerals — pyrite, apatite and zircon — in those portions that are within the ore bodies, decreases sharply in comparison with the content in the bodies of the same dikes that are away from the ore bodies. The observable grains of accessory minerals bear many traces of solution and replacement by secondary products. The crystals are strongly corroded and mottled by leaching, and their surfaces are frequently matt or bear rounded edges. The pyrite is with equal intensity replaced by iron hydroxides. Outside the ore bodies, the crystals of all the accessory minerals are extremely well preserved. All this indicates that the accessory minerals of the lamprophyres within the ore bodies have been subjected to the solvent action of certain reagents. These reagents could only have been the ore-bearing solutions.

3. In the same parts of the lamprophyre dikes which are located within the ore bodies and bear considerable traces of the above described alterations, one may observe a large number of minerals of the so-called superimposed complex — that is, those which have been formed from the ore-bearing solutions as they acted upon the lamprophyres. These minerals are very similar to the ore bodies in their material composition (galena, pyrite, chalcopyrite, barite, fluorite, tetrahedrite and carbonates). Together with these there is a considerable amount of iron hydroxides and of magnetite, which were formed by liberation from the rock-forming iron minerals.

4. Within a very narrow contact zone between the altered lamprophyres and the ore body one observes very small quartz lenses, veinlets, gaps and hollows which disappear rapidly as one moves toward the center of the dike. In the same ore bodies, at the

contacts with the dikes, one may sometimes see strongly altered and metamorphosed xenoliths of lamprophyres.

5. Much more rarely one may observe an intersection of the lamprophyre dikes by thin quartz-carbonate veins containing ore mineralization. Very small apophyses with ore minerals sometimes penetrate the body of the lamprophyres from the main ore bodies.

The Ak-Tyuz and the Kutes-Say deposits belong to the youngest, tentatively Permian, phase of the metallogeny in Northern Kirghizia. They are associated with the post-magmatic activity of the alaskite magma chamber. The vein occurrences of this chamber are (in the order of their injection) granophyres, aplites and various porphyrites (diorite, diabase, etc.). The pre-ore age of the granophyres and aplites cannot be doubted; the porphyrites, as in a number of cases in other deposits, have produced numerous contrary interpretations of their age relationships with the mineralization. There are two basic views: according to one (that of N. D. Tikhomirov and others), the porphyrite dikes are intra-ore; according to the other view, they are pre-ore.

The advocates of the first view believe that the porphyrites were introduced after the formation of the basic polymetallic-rare-metal complex, but before the formation of the latest "oreless" products of the ore process, represented by the quartz, quartz-carbonate and quartz-fluorite veins. The proof of their view they consider to be the clearly visible intersection of the ore bodies by the porphyrite dikes, the lack of any visible alteration, the presence of xenoliths of ore material within the dikes and, finally, the intersection of the dikes by large "oreless" post-magmatic veins of the above-mentioned composition. In actual fact, visual examination does seem to confirm the correctness of this view. The porphyrite dikes occurring in stockwork ore bodies, being formed under the conditions of uninterrupted intra-ore tectonic movements and intensive metasomatism, macroscopically retain their fresh appearance, their primary color and their porphyritic structure. There are no visible traces of alteration or of considerable fracturing. Naturally, if one compares such an excellent state of preservation in the porphyrites with the extraordinarily intensive metasomatism and intra-ore movements, under the conditions of which the ore bodies were formed, one must inevitably conclude that the porphyrites originated later than the mineralization.

This conclusion seems still more convincing if one considers that as a result of metasomatism by high-temperature, very active chemical reagents, the primary surrounding rocks of varied composition (amphibolite schists, paragneisses, biotite hornfels, aplites, pegmatite veins and others) are transformed into a fairly homogenous quartz-chlorite mineralized mass. In individual dikes one encounters angular fragments of mineralized quartz-sericite-chlorite material which would seem to end the discussion of the age relationships between the porphyrites and the mineralization. The presence, within large fracturing zones in the porphyrites, of quartz, quartz-carbonate and quartz-fluorite veins, which are the terminal products of the ore process, would also indicate their intra-ore nature. All these observations apparently are logical and conclusive proof, but their weakness lies in the fact that these observations are all purely visual.

More detailed and thorough investigations unconditionally confirm the pre-ore age of all the porphyrite dikes, as mentioned earlier [14]. Since that time new material has appeared which is still stronger evidence.

1. At the contact with the ore bodies the porphyrites are usually altered to one degree or another. Macroscopically this alteration is reflected in the fact that at the contact itself one may observe a zone of leached and somewhat friable porphyrite. The width of this zone is no more than 1 to 2 millimeters, in very rare cases reaching 2 centimeters, and differs sharply from the remaining part of the prophyrite dike. The color of the porphyrite beyond the leached zone is normal, but considerably less intensive than in the central part of the dike. The color gradually increases in intensity from the contact to the center of the dike.

Microscopic study has shown that the porphyrites are altered not only at the contact itself, but considerably closer to the center of the dikes, although macroscopically this is not visible. The intensity of the alteration gradually decreases away from the contact. In the central parts of the thickest porphyrite dikes one may see completely unaltered areas.

In the initial stage the alteration takes the form of a partial clouding and sericitization of the plagioclase porphyrite phenocrysts and a partial chloritization of the groundmass. Closer to the contact the groundmass is entirely chloriticized, the outlines of the individual minerals disappear and the porphyry phenocrysts are completely serisiticized. In the leached zone the porphyrite completely loses its structure and is transformed into a cryptocrystalline aggregate of chlorite, quartz, sericite, iron hydroxides and other products. The great development of chlorite and quartz is particularly characteristic of this zone.

2. The material composition of the ore body shows no changes at all at the contacts with the porphyrites. In certain very rare cases, in the contact zone itself, the ore mass acquires a more fine-grained structure. In addition, one may sometimes see between the porphyrites and the ore bodies a very fine, microscopically visible, discontinuous layer of sericite.

3. The contacts between the porphyrites and the ore bodies are usually very uneven, with a large number of very small ore apophyses in the contact zone of the dike. The length of these apophyses does not exceed several millimeters. Usually they are localized within the leached zone of the porphyrites, very rarely emerging beyond it into the normally colored porphyrites. These apophyses are composed of quartz, chlorite, and more rarely pyrite and fluorite. Their form is irregular, branching, with swelling and necks, indicating that they originated in the metasomatism of the porphyrite.

4. A very typical feature of the contact zone of the porphyrite dikes is the presence of a series of fractures, which cannot be traced into the ore body but are observed only in the porphyrite. These consist of several more-or-less parallel fractures close to each other and perpendicular to the contact. The individual series of fractures are separated by fairly large intervals.

These fractures usually terminate close to the contact, but nevertheless emerge beyond the limits of the zone of leached porphyrite. Along the fractures one may observe a leaching of the color and a certain loosening of the porphyrite, which are similar to the changes in the leached zone. The fractures are very frequently filled with quartz, but not throughout their whole extent. One has the impression that the quartz lenses are arranged like beads along the fractures. Much more rarely one may also observe finely crystalline pyrite which is an earlier product of the ore-forming process.

Very rarely, along individual fractures, which disappear into the depths of the porphyrites from the above-mentioned series, are formed irregular, nodular accumulations of fine crystalline pyrite. The dimensions of these nodules vary within wide limits, but are usually no more than 2 centimeters in cross section. Similar nodules are joined to each other and to the ore body by a network of fine quartz veinlets.

Some interesting formations in certain of the porphyrite dikes are large nodular accumulations of fine cyrstalline pyrite located within the porphyrite at the contact itself with the ore body. The contours of the nodules are irregular, with a number of tongue-shaped projections toward the center of the porphyrite dike. These tongue-shaped projections are continued by fractures around which the porphyrites have been altered. Such fractures extent some 10 centimeters into the depths of the porphyrite dikes, where they gradually die out.

5. In certain places in the ore body, at the contact with the porphyrite dikes, one may observe xenoliths of porphyrites, which are intensively altered and replaced by ore material and have irregular outlines. Usually such xenoliths are developed in places where the porphyrite material of the dike has been intensively replaced by the ore body.

6. Within the ore body at the contact with the porphyrites one sometimes observes nodular accumulations of fine crystalline pyrite and galena. Their shape is triangular, with their bases facing the porphyrite dikes; from their species, which are directed into the ore body, there frequently extend fine fractures outlined by quartz with occasional fine particles of galena or pyrite. The shape of these nodular accumulations clearly indicates that the ore-bearing solutions were screened by the porphyrite dikes and spread out along the contact. Much less often one observes fine galena apophyses emerging from these nodules into the porphyrite, but not usually going beyond the 2 to 3 millimeter zone of leached porphyrite.

7. Chemical analysis of the porphyrite from the central, slightly altered parts of the dikes and from the zone of leached porphyrite also indicates that the porphyrites were acted upon by the ore solutions. The result of the alterations in the contact zone of the porphyrite was the introduction of silica and alkaline materials and the removal of iron, aluminum, calcium and magnesium from the porphyrite.

8. A study of the heavy fractions of crushed specimens of the porphyrites, including those from macroscopically slightly-altered or almost completely unaltered porphyrites, has shown that within the porphyrites are developed sometimes in considerable amounts, minerals of the secondary complex, whose formations can have occurred only from ore solutions circulating along certain paths in the porphyrite dikes. These minerals (Table 1) are similar to those of the ore bodies: pyrite, galena, kleiophane, marmatite, arsenopyrite, chalcopyrite, fluorite, ankerite, calcite, cassiterite, zirtolite, ferritorite, manazite, carbonates and fluocarbonates of rare earths, and hematite. The total content of these minerals is somewhat greater in the contact parts of the dikes and decreases in the central, less altered areas. The quantatively most abundant

Table 1

Mineralogical Composition of Heavy fractions from Crushed Samples of Porphyrites from the Kutes-Say Deposit (Level 6, Point 6)

Description of porphyrites	Superimposed-complex minerals															Secondary minerals			Primary accessory minerals						
	pyrite	galena	kleiophane	marmatite	arseno-pyrite	chalco-pyrite	native copper	fluorite	cassiterite	monazite	ferritorite	cirtolite	hematite	ankerite	calcite	limonite	chlorite	epidote	magnetite	tourmaline	zircon	anatase	apatite	granite	amphibole
1. Porphyrite is dense and black; intersects carbonate veins	++	+	+	+	−	−	−	+	+	−	−	+	−	++	+	++	++	−	+	+	−	−	−	−	−
2. Porphyrite is black and dense, intersects carbonate veins, is highly fractured.	++	+	−	+	−	−	+	+	+	−	−	+	+	++	++	++	++	−	++	−	+	+	++	−	−
3. Porphyrite is black and dense, intersects carbonate veins, is highly fractured.	++	++	−	−	++	−	−	+	+	−	+	+	++	++	++	+	+	++	+	+	+	−	+	−	−
4. Porphyrite is dense, dark, in parts greatly altered to a light green mass	++	+	−	+	−	−	+	+	+	+	+	+	−	−	+	+	++	−	++	−	+	−	+	−	−
5. Porphyrite is green, greatly altered, intersects numerous carbonate veins	++	++	+	−	+	−	+	+	−	−	+	+	+	++	++	+	++	+	++	+	+	−	+	−	+
6. Porphyrite is highly fractured from the crushed zone	++	++	−	+	+	+	+	+	+	−	+	+	++	+	+	+	++	+	++	−	+	+	+	−	+
7. Porphyrite is dark green, unchanged	++	+	−	−	−	−	−	+	+	+	−	+	−	−	−	+	++	+	++	−	+	+	+	+	+
8. Porphyrite is dense, dark green, intersects thin carbonate veinlets	++	++	−	−	+	−	+	+	+	+	+	+	+	++	++	+	++	−	++	+	+	+	+	−	+

++ basic materials in quantity, + secondary minerals

mineral is pyrite — one of the early products of the ore process. In particular places or individual dikes there is also an increase in the content of galena, arsenopyrite, hematite, zirtolite, monazite, ferritorite, and carbonates and fluocarbonates of rare earths. In their distribution through the rock, the individual minerals are encountered in small quantities. The content of these minerals typically also increases somewhat in these zones of fracturing and brecciation of the porphyrites, which are usually considered to be post-ore, since they bear no traces of visible mineralization. It is true that along these the porphyrites are usually altered and leached, and these alterations are usually visible even to the naked eye, but the advocates of the intra-ore age of the porphyrite dikes have attributed this to the action of surface waters.

One more characteristic feature of these crushing zones should be pointed out: lying sometimes beyond the ore bodies, though in direct proximity to them, these zones also contain a certain amount of superimposed minerals. The artificial introduction of these minerals into the porphyrites is quite out of the question, since the methods used to select the samples and their subsequent treatment were a complete guarantee against these components being present in the test samples.

Everything that has been said is, to our way of thinking, fairly convincing proof of the fact that the porphyrite dikes have been affected ("steamed") by ore-bearing solutions. The latter penetrated into the porphyrites through large crushing zones (pre-ore, and not post-ore) and microfractures, and also into the bulk of the rock through the pores.

9. The primary accessory minerals in the porphyrites — zircon, apatite, anatase, magnetite and pyrite — show traces of considerable solution and alteration. The crystals are often corroded, the faces are often pitted with solution pits, the sides are rounded and the grains themselves are usually lusterless. Pyrite and magnetite are intensively replaced by iron hydroxides, and anatase by leucoxene. These changes, as mentioned in one of our articles [16], may be due to the effect of hypergene reagents alone. In the case in point, these reagents are ore-bearing solutions.

The mentioned types of change in the porphyrites are observed only within stockwork ore bodies, and in certain cases in direct proximity to them. At long distances from the ore bodies are porphyrite dikes do not undergo any such changes.

What has been said is fairly convincing proof of the post-ore age of the porphyry dikes at the Ak-Tyuz and Kutes-Say deposits. We will now try to explain the macroscopically observed arguments which are used by supporters of internal-ore age of porphyrites to prove their point of view.

1. References to the lack of any change in the porphyrites, as we have already seen, are invalid. The porphyrites have been altered and quite radically. It is true that this shows up rather poorly from the macroscopic point of view, but it must nevertheless be taken into account that, as experience shows, the porphyrites are, chemically speaking, a relatively inert medium, which reacts only slightly to the chemical effect of the ore-bearing reagents. This characteristic feature is manifested literally in all deposits, but it is only in the places where the effect is accompanied by crumbling of the porphyrites that its results can be macroscopically detected. Hence, however much certain investigators [7] may try to prove that our views on the inert nature of porphyrites are wrong, study of the North Kirghizia deposits proves that our conclusion is correct.

2. The visible intersection of the porphyrite dikes and ore bodies and their intersection, again, by veins of late "non-ore" products of the ore process, as we have seen, does not entirely correspond to the actual state of affairs. In actual fact, the porphyry dikes contain pre-ore weakened sectors, in which the secondary minerals are present in a slightly greater number, or along which the products of the earlier stages of the ore process (quartz, pyrite) penetrate into the porphyrite bodies, but it is actually the later products which show a more clearly marked cut shape. This is due to the nature of the intra-ore tectonic movements, whose intensity at the initial stages, despite their continuity was comparatively small and only became much greater at the end of the ore process. On account of the considerable plasticity of the porphyrites, the small tectonic movements had practically no effect on them. Whereas all other rocks were crushed by these movements and the ore-bearing solutions circulated through the fractures, intensively replacing the enclosing medium, the porphyrites remained monolithic and did not crumble. The intensity of the tectonic movements, which increased toward the end of the ore process, enabled them to cover the porphyrite dikes as well. It was in the fissures which formed in the process that the later products were localized.

3. A detailed study was made of the "xenoliths" of the ore body in the porphyrites. The study showed that there definitely were xenoliths in the porphyrites, not from the enclosing rocks (in this particular case, granophyres). During the ore deposition these xenoliths were, like all the enclosing rocks,

replaced by ore material. The replacement was selective and involved only the xenoliths, while the porphyrites remained practically untouched. Some mineralized xenoliths were joined together and also with the ore body as very fine fracture channels, along which lenticular quartz segregations are sometimes observed. Small fractures also lead back from the xenoliths into the dikes. It should be said that these xenoliths are near the porphyrite-dike contacts. Thus the evidence in favor of the intra-ore age of the dikes was really based on external features and proved incorrect.

We will now deal with two examples in which there really were vein formations of both pre-ore and post-ore age, in an attempt to explain the phenomonen.

The Boordu deposit is assigned to the tentatively Devonian phase of metallogenisis. Here the ore bodies are localized in a major fault zone on the boundary between Caledonian porphyritic plageoclase granites and pre-Cambrian gneissic alaskite granites. Besides polymetallic ore bodies, numerous vein rocks of different composition, which are evidently from the same magmatic phase, are assigned to the fault zone. One can single out among them, in order of introduction, quartz porphyries, dacite porphyries, granosyenite porphyries, diorite porphyrites and, finally, diabase porphyrites. This sequence is proved by the fact that each preceding formation is intersected by the following one. Also assigned to this zone is a strip of neo-ore alteration, shown by the intensity of beresitization. Beresitization and ore mineralization embrace both plagioclase granites and gneissic alaskites, as well as the quartz porphyries, dacite porphyries and granosyenite porphyries. The pre-ore age of these vein rocks can thus be proved from this fact alone.

It is more difficult to explain the age relations of the mineralization and the porphyrite dikes. Just as at the Ak-Tyuz and Kutes-Say deposits, the porphyrites here show practically no macroscopic traces of alteration and intersect the ore bodies fairly clearly. Thus many investigators (N. D. Tikhomirov, A. T. Pochernin and others) consider them post-ore. Indeed, the external appearance of these rocks is fairly fresh. The diorite phorpyrites are gray-green or dark green rocks with clearly observable scattered phenocrysts of plagioclase, hornblende and more rarely, pyroxene in an aphanitic groundmass made up of quartz, plagioclase, orthoclase, apatite, zircon, magnetite and pyrite. The diabase porphyrites are gray or dark gray, and have an aphanitic texture with clearly-marked andesite phenocrysts. The darker minerals are represented by pyroxene and biotite. The basic mass is composed of plagioclase and darker minerals.

A detailed microscopic study of the porphyrites, particularly a mineralogical investigation of the heavy fractions of crushed samples, shows that the opinion of previous investigators regarding their post-ore age is erroneous. In actual fact the diorite and diabase porphyrite dikes, like the earlier representatives of the vein complex are pre-ore.

Microscopical study shows that the fresh appearance of porphyrites is seen only beyond the ore field, while within its bounds the porphyrites, like the other rocks, show traces of alteration by ore-bearing solutions, although the changes are not detectable macroscopically as easily as in other types of rocks. The changes show up as chloritization of the darker components and sericitization of the feldspars. In both cases a considerable amount of carbonates was formed.

Mineralogical study of the crushed samples showed that all the porphyrites to some extent contain secondary minerals — pyrite, sphalerite, galena, kleiophane, chalcopyrite fahlerz, ankerite and other minerals (Table 2).

From our own observations, the primary accessory minerals shows traces of the effect of hydrothermal solutions. The zircon and apatite were dissolved by iron hydroxides, and the pyrite and magnetite were both dissolved and replaced by them. The crystals of these minerals are very often pitted with solution pits, become lusterless and rounded, and sometimes turn into irregular, strongly-corroded grains. The porphyrite samples taken from the dikes beyond the ore field do not show any such changes in the accessory minerals in the altered porphyrites, within the actual ore zone, is much smaller than in the same dikes outside the sphere of influence of the ore-bearing solutions. The content of absolutely all minerals is reduced, but apatite and pyrite are the most strongly dissolved.

It follows from what has been said about the effect of post-magmatic ore-bearing segregations on the porphyrites, that there is not only alteration of the rock-forming minerals and creation of new secondary minerals in the porphyrites, but also considerable dissolution and alteration of the primary accessory minerals.

Everything that has been said on the change in the accessory minerals due to the effect of ore-bearing solutions on the porphyrites fully applies as well to other, earlier vein rocks and enclosing rocks, whose accessory minerals undergo similar changes. Thus, the facts we have quoted are sufficient proof, in our opinion, of the pre-ore age of all the vein formations in the Boordu deposit.

Table 2

Mineral Composition of Heavy Fraction of Porphyrite Crushed Samples from the Boordu and Taldy-Bulak Deposits

Place from which taken	native copper	native lead	pyrite	galena	sphalerite	kleiophane	chalco-pyrite	arseno-pyrite	molybden-ite	tetrahedrite	bornite	chalcosite	covellite	marcasite	fluorite	magnetite	limonite	calcite	ankerite	malachite	cerussite	zircon	leucoxene	apatite	barite	gypsum	aragonite	chromite
1. Boordu deposit, drift 1, strat. 16	–	+	8.0	0.6	+	+	+	–	–	+	–	+	–	–	+	–	+	+	353.0	–	–	+	0.3	1.3	–	–	–	–
2. Boordu deposit, drift 1, strat. 23	–	–	0.07	0.7	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+	–	+	+	–	–	+	–	–	–
3. Boordu deposit, drift 1, strat. 17	–	+	1.3	1.5	+	+	–	–	–	+	–	–	–	–	–	+	+	+	360.0	–	+	–	–	+	–	–	–	–
4. Boordu deposit, drift 1, 2b	+	+	3.2	0.03	+	+	0.1	+	+	+	–	–	–	+	–	0.2	–	+	–	–	+	0.04	–	+	0.08	–	–	–
5. Taldy-Bulak deposit, drift 5	–	–	2.4	+	+	–	+	+	–	0.24	+	+	+	–	–	1.0	2.5	+	31.0	+	3.0	+	–	–	+	+	+	+
6. Taldy-Bulak deposit, ditch 6	–	–	1.6	0.5	+	+	+	–	–	+	–	+	+	–	–	0.2	1.0	+	3.0	+	1.0	+	–	–	0.2	–	–	–

Figures are given in $\% \cdot 10^{-3}$; the + indicates the presence of single grains of a mineral.

Apart from the above-mentioned vein rocks, this deposit also contains syenite-diorite dikes belonging to the tentatively Permian phase of igneous activity. In their composition (particularly the accessory minerals) these differ sharply from the dike rocks and have many features in common with the tentatively Permian syenites and granosyenites, which are very common in the regions adjacent to the deposit.

According to G. P. Lobogoshchinskaya (1957), the dikes of these rocks are post-ore. They clearly intersect the ore zone, and in so doing metamorphose the ore mass (recrystallize it) in direct proximity to themselves. The veins are almost completely unchanged. It is true that the rock forming minerals show certain changes due to autometasomatism, but the accessory minerals are completely fresh and show no traces of dissolution or replacement by secondary minerals. Secondary minerals are completely lacking in these dikes. Thus vein-rock dikes at the Boordu deposit belong to a completely different, earlier magmatic phase, as compared with the pre-ore likes and the mineralization itself.

Our research at the Kurgan deposit is at the present time sufficient to establish with reliability two age mineralogical-geochemical types of ore formation which are genetically interconnected: 1) with the activity of the tentatively Devonian granite ore-bearing magma chamber — this type is represented by polymetals; 2) with the activity of the tentatively Permian alkaline ore-generating magma chamber — this type is represented by rare-metal mineralization. Both types occupy more or less the same space.

The deposit has a fairly well-developed vein complex of a variety of rocks: quartz porphyries, diabase porphyrites, aegyrite syenites, quartz syenites, syenite aplites, trachidolerites and certain others. With regard to the age relationships of the vein-complex rocks, many investigators feel that the first two types relate to the older magmatic phase, while the others, which are alkaline, are representatives of a more recent, tentatively Permian phase.

The commonest rocks associated directly and physically with the ore bodies are the diabase porphyrites, aegyrite syenites and syenite aplites. We will not deal at present with their age relationship with the mineralization.

The relationships of the diabase porphyrites and polymetallic mineralization (and consequently the more recent, rare-metal mineralization) are comparatively simple and give no grounds for disagreement. Both geological and mineralogical data indicate the pre-ore age of the porphyrites, but opinions differ on the relationship of the alkaline dikes and the minealization, both polymetallic and rare-metal types. Most investigators consider that the aegirite-syenite and syenite-aplite dikes are also pre-ore with respect to both the rare-metal and polymetal mineralization. They thereby assign the polymetallic and rare-metal mineralization to one metallogenic phase which stems from the tentatively Permian alkaline ore-producing magma chamber. Thus the chief conclusion drawn by these investigators is that the age of all the vein formations at the Kurgan Deposit is pre-ore.

Our own research indicates something different, namely that the aegiritesyenite and syenite-aplites are pre-ore with respect to the rare-metal mineralization, and post-ore with respect to polymetallic mineralization. On the basis of this we have singled out the products of these two metallogenic phases at this deposit. The following facts are offered as evidence.

The rare-metal mineralization is very often superimposed on syenite-aplite and aegirite-syenite dikes; the latter often play the part of ore bodies, and in so doing undergo radical alteration. There is no need for any great proof of the pre-ore age of the alkaline dikes relative to the rare-metal mineralization. Furthermore the aegirite-syenite and syenite-aplite dikes intersect the ore-bodies of the polymetallic complex at certain points, and at the contacts the ore material undergoes recrystallization. But the dikes themselves do not undergo any changes, nor does their mineral composition (including accessories). Moreover, the rare-metal zones, which are genetically closely associated with syenite-aplites, intersect the polymetallic ore bodies.

We believe that these facts are proof that polymetallic mineralization was formed much earlier than the alkaline dikes and the rare-metal mineralization associated with them.

CONCLUSIONS

Despite the apparent validity of simple visual observations, they do not always solve the problem of the age relationships of dike-complex rocks, particularly the dikes of basic rocks (various porphyrites, etc.) and the post-magmatic mineralization. The most important reason for this obscurity in the relationship, in the case of the porphyrites, which is often not taken into account by investigators, is in our opinion their high chemical inertness (compared with other types of rock), considerable plasticity and viscosity. The first of these makes the porphyrites react less than other, more acidic rocks to the effect

of high-temperature, chemically highly-active reagents containing concentrations of fluorine, chlorine, water and carbon dioxide, not to mention low-temperature hydrothermal solutions. Whereas the acidic dikes (aplites, granite-porphyries, quartz-porphyries) undergo complete post-magmatic alteration, the porphyrie dikes remain almost completely unchanged macroscopically; microscopic study also shows only slight traces of alteration.

The second feature (plasticity) enables the porphyrites to react to all the slight tectonic movements which often accompany the ore process, showing almost destructive effect. Whereas other types of enclosing rocks crumble during such movement, making their near-ore alteration more rapid and more complete, the porphyrites remain monolithic, and it is only major tectonic stresses which can effect them. Although these large movements occurred during the ore process, as we saw from the Kutes-Say deposits, the post-tectonic mineralogical associations may be localized in porphyrites in the fracture zones, giving the impression of an intra-ore age.

To obtain simpler concepts of the age relationships of the dike rocks and the mineralization, in addition to external, purely visual observations, we must make a number of other, more detailed investigations. We recommend the following methods, which were used in our own work, and which gave, in our opinion, fairly good results.

a) Detailed study (centimeter by centimeter) of the contact zone between the ore body and the dikes in the vein rock using microscopic investigation of transparent thin sections and polished surfaces. Here attention should be paid to the nature and degree of alteration of the vein rocks and ore bodies at the actual contact, and also to the shape of the contact, the presence of xenoliths, apophyses, stains, veinlets, notches both in the vein rocks and the ore bodies, and the presence and shapes of ore-mineral segregations.

b) Detailed microscopic study (thin sections and polished sections) of the igneous dikes both within the ore body and outside it. The frequency of observation points in the dikes is chosen in accordance with their thickness, the nature and extent of the ore process. An essential condition is to increase the observation points when approaching the dike contacts. If necessary, microscopic investigation should be accompanied by chemical analysis to detect the chemical nature of the change. Here attention should be given to determining the nature and intensity of the change in the outward morphological features and the composition of the dikes, the physical distribution of products with various degrees of alteration, the presence of fractures, the mineral filling of fractures, their abundance, size, and the various parts of the dikes in which they are distributed.

c) Detection and study (usually in polished sections) of fracture zones in the dikes. Here attention should be given to the orientations, size and mineral filling of the fractures or fracture zones, and alteration of the rock near the fractures.

d) Mineralogical study of heavy fractions of crushed samples of vein rocks, taken both within and outside the ore body. The point of this method is to detect differences in the sequence and nature of the change in the qualitative and quantitative composition of secondary minerals in different parts of the dike, within and outside the outside the ore body, near the contact with the body and in the more central parts of the dike. The number of crushed samples and the places from which they are taken depend upon the specific task. During subsequent study of the actual heavy fractions, the investigator's attention should be directed first to the primary accessory minerals and second to the material composition of the superimposed complex.

In the case of primary accessory minerals, each sample is examined for their total content, the number of individual mineral species the degree and nature of change in them (solution, corrosion, replacement by secondary products, etc.). All this provides material for a comparative analysis of the distribution of accessory minerals in different parts of the dike body.

In the case of the superimposed complex, each example is examined for its mineral composition, quantitative development of different mineral species, morphological features of same and chemical composition (from spectrum analysis). All this is compared with the relevant data for the ore body. The similarities and disimilarities between the composition of the ores and the superimposed complex are established thus. The resulting enable us to make a comparative analysis of the physical distribution (in thickness, extent and dip of the dikes) of certain secondary minerals, and allows us to draw interesting conclusions on the differential movement of various components.

Other methods of investigation of dike rocks and ore occurrences in the same space could probably be suggested, but those described above, as shown by our own experience, are quite sufficient for a simple solution to the problem of the age relationships of dikes and mineralization.

We personally believe that, of all the suggested methods, mineralogical-geochemical

study of heavy fractions is the simplest for the question at hand.

If the dike contains a superimposed complex of minerals, if the primary accessory minerals bear traces of dissolution and replacement by secondary products, and if their over-all content is smaller than in the parts of the dike outside the ore body, this undoubtedly means that the dike is of pre-ore age, since no process other than hypergene can bring about these changes. But alteration of the rock-forming minerals of the dikes may sometimes be due to surface waters.

2. The above data for different deposits in Northern Kirghizia leads us to believe that the post-magmatic process which produced the basic concentration of minerals in each ore-bearing magmatic phase takes place after formation of all the dike derivatives of this phase and of the same ore-bearing magma chamber. Thus in each magmatic phase (in a broad sense) the dike complex is pre-ora as far as post-magmatic mineralization is concerned. We should make the proviso, nevertheless, that this refers to the products of the post-magmatic differentiates from the deeper parts of the chamber and only appear after the basic intrusive bodies have come into existence. The same post-magmatic occurrences, which are often to some degree ore-bearing) whose formation is associated with the actual origin of the intrusive bodies themselves (pegmatites, skarn, hornstone, autometasomatic zones and sometimes greisens, etc.), may be earlier than the dike-complex occurrences.

Every truly post-ore dike met in any deposit, to our way of thinking, relates to another, more recent magmatic phase, which need not necessarily be an ore-bearing one, but which is fully manifested in the area of the given deposit.

We consider that this regularity of distribution applies to other parts of the Soviet Union besides Kirghizia.

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A VOLCANOGENIC STRATUM IN THE CENTRAL CAUCASUS AS A POSSIBLE SOURCE OF SEDIMENTARY LEAD AND ZINC DEPOSITS[1]

by

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I. SOME DATA FROM THE LITERATURE

Over the last few years a number of extremely interesting articles have been published in our geological literature on the theoretical possibility of sedimentary formation of lead and zinc deposits.

Those actively supporting this view, in particular M. M. Konstantinov [7], suggest the probable existence in nature of conditions favorable for the accumulation of lead and zinc in the waters of closed or semi-closed epicontinental seas with abnormally high salt contents, and consider that the primors source of lead and zinc in the epicontinental waters containing these metals are the continents. Owing to the abrasive activity of the salt seas, the metals were eroded on the continents either from sedimentary rocks containing disseminated deposits of lead and zinc, or else as surface-destruction products of the polymetallic deposits already existing there.

Other investigators (A. G. Betekhtin, V. I. Smirnov, A. N. Legkov and others), though not denying the general possibility of the formation of sedimentary deposits of lead and zinc, have made a number of valuable critical comments, particularly regarding the migration and accumulation of these metals in the hypergene zone [4, 11, 13]. Smirnov considers zinc and lead concentration under marine conditions to the unlikely, in view of the fact that rivers transfer comparatively small portions of these metals, corresponding to native deposits only, and also the fact that they are covered by enormous stretches of sea water. He questions the feasibility of the existence of large sources of lead and zinc on the continents which under favorable conditions could produce sufficient metals to form sedimentary lead-zinc deposits.

In 1955, A. A. Kudenko [9] came to the conclusion that in discussing sedimentary ore formation scientists completely groundlessly ruled out the extrusive processes, although according to a number of investigators (A. Ye. Fersman, S. A. Borovik, V. I. Vlodavets and others), appreciable quantities of a number of metals (including copper, tin, lead and zinc) were detected in the eruption products of present-day volcanoes and that, given favorable conditions, it was very possible that these heavy metals had been carried considerable distances by slightly acidic volcanic waters. The author feels that search for sedimentary lead and zinc deposits should be concentrated, first and foremost, in limestones, which were usually deposited after periods of intensive volcanism, and that the greatest attention should be paid to bituminiferous rocks.

Interesting data on the sorption of lead, as well as the diagenesis of lead and zinc-containing sediments, have been published by N. I. Khitarov, Ye. V. Rozhkovaya and O. V. Shcherbak [12].

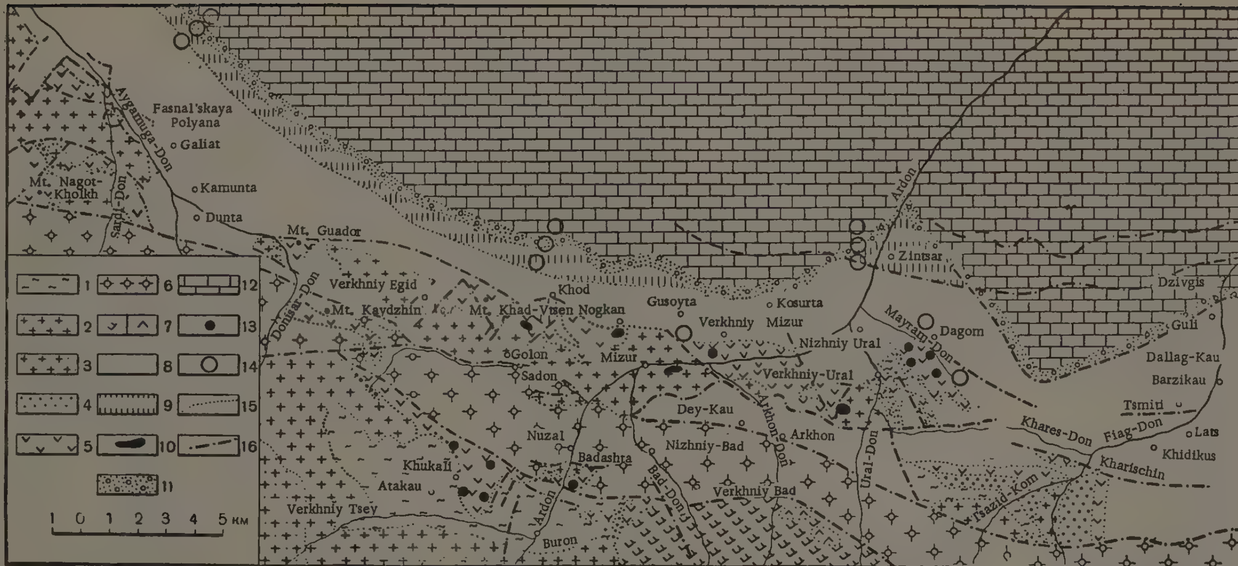
II. EFFUSIVE AND PYROCLASTIC ROCKS IN THE VOLCANOGENIC STRATUM OF THE LOWER LIASSIC

For a number of years I have studied the geology and metallogeny of the Sadonian polymetallic zone in the Central Caucasus [3], and made a number of observations on the possible main source of sedimentary lead-zinc mineralization associated with the extrusive and pyroclastic rocks in the volcanogenic[2] stratum (see map).

It is well known that during the lower Liassic (probably in the upper Sinemurian) in the Central Caucasus, and particularly in the mountainous region of Northern Osetiya,

[1] Vulkanogennyy gorizont tsentral'nogo kavkaza kak vozmozhnyy istochnik osadochnykh mestorozhdenii svintsa i tsinka.

[2] L. A. Vardanyants (5) and G. D. Azhgirey (1) call this statum keratophyric.



Geological map of the Central Sadon Anticlinorium

I. Paleozoic rocks: 1) crystalline schists and gneisses of lower and middle Paleozoic; 2) middle Paleozoic granites; 3) granodiorites, diorites and other intrusive rocks of upper Paleozoic.

II. Liassic rocks: 4) graphite-conglomerate stratum (conglomerates with layers of sandstone, argillaceous, carbonaceous and graphitic schists) of the lower Liassic; 5) volcanogenic stratum rocks (mantles of albitophyres, porphyrites, dacites and other rocks and their tuffs, tuff breccias and agglomerates), lower Liassic; 6) slaty schists, sandstones, quartzites with blanket deposits of diabases, prophyrites and their tuffs of the middle Liassic; 7) slaty schists, quartzites, rarely conglomerates of lower and predominately middle Liassic (on the right) with stocks and sills of pre-Toarcian diabases (on the left); 8) sandstones, galena conglomerates, sandy-clay shales of the upper Liassic.

III. Dogger rocks: 9) clay shales with layers of sandstone and Dogger spherical siderite concretions; 10) granodiorite-porphyry of stock facies and albitophyres of dike facies of pre-Callovian age.

IV. Malm rocks: 11) ferruginous limestones and conglomerates, limonites, sandy limestones, and clay shales of the Callovian; 12) limestones with layers of dolomite and thin layers of marl and limestones of the Oxfordian, Lusitanian, Kimmeridgian and Tithonian Malm strata, 13) areas from which volcanogenic rock samples of the lower Liassic were taken; 14) areas requiring investigation in order to ascertain lead and zinc mineralization of sedimentary origin; 15) boundaries between rocks, strata, etc.: 16) tectonic dislocations.

there was intensive volcanic activity, which apparently followed the incipient downward tectonic movements so very characteristic of the lower Liassic epoch. The violent volcanic activity of this time is shown by the thick accumulations in certain regions of volcanic formations of mixed extrusive-eruptive formations, forming a number of separate stratified volcanic cones at a considerable distance away from each other. This volcanic activity resulted in the so-called volcanogenic stratum, developed over an extensive area of Gornaya Osetiya in the shape of a zone more than 40 kilometers long and 2.0 to 8.0 kilometers wide, with an average width of about 6 kilometers.

It should be pointed out that in this zone, which stretches from the Mount Kazat-Khokh meridian eastward approximately as far as the village of Kharischin (on the river Fiag-Don), the volcanogenic stratum rocks do not crop out continuously along the surface. Embedded between crystalline basement rocks (with a lower Liassic graphite-conglomerate stratum overlying it here and there) and the sandy-argillaceous deposits of the upper Liassic, the volcanogenic stratum occurs, as it were, in separate islands, with flows and pyroclastic formations of different thickness. This scattering is explained by erosion, mainly recent, which has exposed the volcanogenic stratum to the surface in the uplifted blocks, whereas in the lowered parts its rocks have remained covered by comparatively thick sandy-argillaceous deposits of the upper Liassic. These areas of the volcanogenic stratum are exposed (from west to east): in the region of Mt. Kazat-Khokh, in the middle reaches of the River Sardi-Don, in the region of the Fasnal'skaya Polyana (River Sanguti-Don), on Mt. Guador, in the region of Mt. Kaydzhin-Khokh, on the River Khod-Vtsek, around the villages of Nagkau and Khukali and the hamlet of Badashta, south of the village of Verkhniy Bad, at the mouth of the River Arkhon-Don, on the watershed between the Rivers Arkhon-Don and Unal-Don, around the village of Verkhnity Unal, on the upper reaches of the River Mayram-Don, on the Khurkhchinta Ridge, and around the village of Kharichin (River Fiag-Don). The total area of the outcrops of volcanogenic rock at the surface in this zone is 160 kilometers^2.

The pyroclastic formations of the volcanogenic stratum are represented by a complex of effusive rocks (albitophyries, porphyrites and dacites) and their tuffs, tuff breccias and agglomerates; tuffaceous sandstones sometimes occur among them. On the margins of the volcanogenic zone, for example in the Kazbek and particularly the Aygamugi-Don (Digorye) regions, the pyroclastic and flow formations are interbedded with normal sedimentary ones, representing a very unusual pyroclastic and partially sedimentary clastic accumulation. In the Aygamugi-Don basin, for example, according to S. S. Kuznetsov [10], the volcanogenic stratum consists of tuffs, beds of clay shales and quartzites. In sections along the Sanguti-Don River it is covered by a pack of clay shales and sandstones, in which plant remains have been found in the form of fragments of carbonized tree trunks (up to 0.5 meters in diameter). This layer apparently belongs to the upper Liassic.

The interbedding of effusive-pyroclastic formations with normal sedimentary rock shows that the volcanic region, which may be called the Ara-Don region after the River Ara-Don, was evidently an archipelago consisting of a number of islands of volcanic origin, in the upper Sinemurian stage. The presence in this region of a number of areas of volcanogenic rock of considerable thickness, several hundreds of meters (350 to 450 meters around the village of Nogkau and 600 to 700 meters in the area between the Unal and Arkhon Rivers, the usual occurrence of agglomerate layers in these areas and the uneven thickness of the volcanogenic stratum, which varies considerably over such comparatively short distances as 1.5 to 2.0 kilometers (for example, the mouths of the Rivers Arkhon-Don and Sular-Don), all suggest that there were several chief centers of volcanic outflow, in the form of a number of stratified volcanos, throughout all the Ara-Don volcanic region.

The volcanogenic outcrop zone is roughly parallel to the equator and coincides with the axial zone of the the Sadon anticlinorium. The volcanogenic stratum is exposed on the surface either in the the crests of the anticlinical folds or else in synclinal troughs with undulating hinge lines of branchiform bends, but most frequently in the flanks of these folds in the axial zone of the Sadon anticlinorium. The only exception is a small number of outcrops around the village of Khukali, the hamlet of Badashda and the village of Bada; all these outcrops belong to the northern flank of the Kazbek-Tepla anticlinorium.

In studying the petrographic composition of the rocks making up the ore fields of certain polymetallic deposits [4] it was observed that the rocks of the volcanogenic stratum, predominantly the flows, almost everywhere contain distinct disseminated pyrite, and less distinct or abundant sphalerite and galena. No traces of hydrothermal activity in the extrusives containing the diseminated ores were noted (see Table 1).

Thus, the mean content of economically valuable components from 9 group samples from 52 pieces, taken from 52 deposits,

Table 1

Results of Chemical Analysis of Rocks from Volcanogenic Stratum

Number	Place from which sample taken	Composition of sample	Content in %	
			lead	zinc
1	One km southeast of Khukali village	Five pieces of albitophyres from 5 outcrops (113A, 114A, 115, 116 and 121)	0.03	0.08
2	One km northeast of Khukali village	Five pieces of albitophyres from 5 outcrops (238, 242A and B, 245 and 246)	Traces	0.08
3	Two km northeast of Ata-Kau village	Six pieces of albitophyres and their tuffs from six outcrops (249, 326, 358, 370, 383, 513)	0.05	0.10
4	One km east of Ata-Kau village	Four pieces of albitophyres from 4 outcrops (511, 519, 546 and 416)	Not det.	0.04
5	Two km east of Mizura on left bank of Ara-Don	Two pieces of albitophyres from 2 outcrops (305 and 181)	0.07	0.08
6	Basin of upper reaches of Mayram-Don (left bank of Mayram-Don)	Six pieces of albitophyres and their tuffs from 6 outcrops (217, 225, 241, 156, 213C, 242)	0.05	0.10
7	Basin of upper reaches of Mayram-Don (Akhshertyrag area)	Three pieces of phorphyrites from 3 outcrops (172, 172A, 227)	0.07	0.06
8	Akhshertyrag Ridge (0.05 km south of test area 7)	Nine pieces of albitophyres from 9 outcrops (196B-C, 214, 217, 218, 230-2. -4, 232)	Not det.	0.10
9	Basin of middle reaches of Mayram-Don (left bank opposite Dagoma village)	Twelve pieces of albitophyres from 12 outcrops (105, 106C, 107A, 172B-C, 181A-B, 222, 228, 237, 238 and 239)	0.05	0.08
		Mean arithmetic value from 9 samples[a]	0.035	0.08

[a]All pieces taken from samples were of equal size.

amounts to 0.035% lead and 0.08% zinc, and generally speaking embraces a comparatively large area (more than 4.0 kilometers^2) of outcrops of the volcanogenic rock.

Some samples which this writer took in 1951 from completely unaltered hydrothermal albitophyres at the Buron mine, in the locality of Badashta, on the right slopes of the Ara-Don valley, showed similar results when analyzed for the lead and zinc content.

The data in Table 1 accurately reflect the lead and zinc contents in the effusive rocks of the volcanogenic stratum. These contents, though generally small, are nevertheless 17 times larger than the lead clarke (0.002) and 4 times as much as the zinc clarke (0.02) of the earth's crust.

It should be pointed out that on Mt. Guador, in the eastern part of the Digorye, within the Sadon polymetallic belt, M. I. Itsikson [6] tested the mantle of albitophyres (keratophyres), which extend over an area of about 2000 meters^2 and had a thickness of up to 50 meters. Analysis of the average sample, composed of equal volumes of specimens taken at regular distances over the entire area, showed a lead content of 0.46%, a zinc content of 0.74% and a tin content of 0.15%. The effusive rocks tested by Itsikson, if their analyses are reliable, place them in the class of disseminated ores of economic significance.

III. CERTAIN PRECONDITIONS FOR POSSIBLE FORMATION OF SEDIMENTARY LEAD AND ZINC DEPOSITS IN THE CENTRAL CAUCASUS

After its formation the volcanogenic stratum was repeatedly weathered, eroded and buried by deposits, as a result of the transgressions of the Jurassic sea. The first, most intensive erosion took place in the pre-Toarcian stage,

with subsequent deposition of upper Liassic (Toarcian) conglomerate-sandy-clay deposits on the eroded surface of the volcanogenic stratum. The stratum was again bared by pre-Aalenian erosion and buried by deposits from the Aalenian Sea. In the Jurassic period the stratum was exposed for the third time by the intensive tectonic movements in the pre-Callovian period, the erosion at this time being comparatively deep and in certain regions (for example, in the region of Mt. Uaza-khokh) even exposing the rocks of the ancient crystalline basement. Afterwards, as a result of the transgression of the upper Jurassic Sea Callovian marine sediments were deposited on the eroded Pre-Callovian surface. Finally, during the present period, the volcanogenic stratum was again exposed in certain parts, corresponding to the elevated tectonic blocks of the Sadon and Kazbek-Tepla anticlinoria.

Thus during the Jurassic period the volcanogenic stratum was thrice exposed, weathered and eroded by the sea. It is therefore quite natural to ask whether the ore components of the volcanogenic rocks, in particular lead and zinc, which undoubtedly got into the sea basin, could have been deposited under favorable circumstances and produced industrial concentrations. Such favorable conditions for the deposition of zinc and lead, as far as is known from the very skimpy data available, did actually exist. For example in the Toarcian sandstones exposed in the mountainous part of northern Osetiya, namely the environs of Tsamad village, according to data from the Sevkavtsvetmetrazvedka" Trust, often contain from 0.001 to 0.01% of lead. According to a report by V. M. Pats, chief geologist of the Northern Caucasus Geological Administration, at the All-Caucasus Lead Conference held in October, 1954, in Ordzhonikidze, among the Aalenian terrigenous deposits in the Circassian Automonous Oblast' there was discovered one sector containing intensively orcherized sandy-argillaceous deposits with a comparatively high lead concentration (up to 1.0%). According to a verbal communication from D. V. Abuyev, chief engineer of the North Caucasus Geological Administration, the Callovian sandstones in the Tyzyl region contained sedimentary occurrences of lead ores; the lead content of samples of these sandstones was from 0.1% to 0.9%. In 1955 and 1956 L. N. Plamenevskiy established the universal presence of lead in amounts up to 0.05%, and of zinc up to 0.08%, along with an appreciable quantity of copper, in the Callovian and Oxfordian limestones along the River Terek, and also in the Ara-Don basin.

At the present time, none of the geologists working on the theory of the formation of sedimentary deposits has any firm opinion on the main source of the lead. M. N. Konstantinov [7] for example considers that the main sources of lead for the sedimentary deposits were the continents with areas of lead ore of igneous origin, or galena-containing sedimentary rocks. V. I. Smirnov [13] acknowledges the possibility of lead deposits having formed by sedimentation, although the prime source of lead on the continent is not known. Thus both authors doubt whether the main source of lead during the formation of the sedimentary deposits could be igneous rocks, as in the case considered here, where lead- and zinc-containing effusive rock are represented by a mantle of albitophyres spread over a considerable area.

On the basis of what has been said, we consider that the main source of zinc and lead in the Central Caucasus may be the effusive (albitophyres) and pryoclastic rocks of the volcanogenic stratum, containing galena and sphalerite as the permanent accessory minerals (besides pyrite). At the present time the present author, in view of the insufficient study of the migration conditions for lead in the hypergenesis zone, has no information on the way lead moves in marine waters, on its concentrations or on the favorable conditions under which the formation of economically valuable sedimentary lead deposits is possible. The chemical nature of the erosion and solution of the lead, its transportation by sea water and accumulation in sediments under the specific conditions of the Central Caucasus is of very great topical importance.

It is therefore essential as soon as possible to make a thorough lithologic study and examination of samples of the upper Liassic, Aalenian, Callovian, Oxfordian and more recent (Malm and Cretaceous), from the standpoint of possible detection of large areas of sedimentary ore containing economically significant lead and zinc deposits.

Above all we must make a thorough study of the lead in the sandstone beds of the upper Liassic on the right bank of the River Mayram-Don (around Dagom village), and on the left bank of the middle reaches of the Sularte-Don valley, of the sandy-argillaceous Aalenian deposits along the River Ara-Don, in the environs of Khod village and on the right bank of the River Urukh and of the Callovian deposits common in the Ara-Don basin, and particularly the River Urukh, which have long excited the attention of investigators by the presence of lead-containing brown sedimentary iron-ore. Finally, a study must be made of the lead content of the Oxfordian limestones, and the lead concentration as a function of the terrigenous sediment content, and also the bituminosity, should be determined.

Furthermore a more detailed study should be made of volcanogenic rocks, first and foremost the albitophyres from Mt. Guador, in which Itsikson [6] discovered an industrially significant content of lead, zinc and tin, in order to ascertain the scale of this extremely interesting mineralization in igneous extrusives.

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BRIEF COMMUNICATIONS

THE STRATIGRAPHIC IMPORTANCE OF SPORE TAXONOMY[1,2]

by

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The aim of sporology, in the narrow sense of the word, is to establish the genetic relationships between dispersed spores (sporae dispersae) and their subsequent inclusion into a natural (morphological) system of vegetation.

This can partly be done by comparing the dispersed spores with each other, or with others found in situ. But for the time being most types of dispersed spores are unrelated to any natural system of vegetation, or else are only included conditionally. Hence, to make a systematic classification of all dispersed spores at the present time we have to use a so-called "morphographical system." Morphography (called sporography when applied to the study of dispersed spores) is the description and classification of dispersed spores from their external characteristics, without establishing the genetic relationships between the objects observed.

The morphographical system is the basis of a morphological investigation. This makes it possible to compare dispersed spores in situ and to classify several species of them, accordingly, in a morphological system of vegetation.

In stratigraphic correlations based on the study of dispersed spores use is made primarily of morphographical data. The statistical method, which is usually called pollen analysis (I would call it "spore analysis," since pollen is essentially spores) has some limited use when applied to coal deposits. Working methods may be modified according to the aims pursued by the sporologist (in the widest sense of the word). The solution of narrowly stratigraphic questions requires a different sort of discussion than does the determination of the relationship between the separate organs of the plant.

Let us dwell on some of the principles involved here.

1. In determining the generic relationship of the plant as a whole, different parts of it are of different diagnostic importance.

2. Hence the stratigraphic importance of different parts (organs) of the same plant genus (the stratigraphic incongruence of the organs) is also dissimilar.

3. Different genera and species of organs and structures usually retain their different stratigraphic importance even in these particular cases in which generic relationships can be established between them.

4. In solving theoretical problems of botany, it is true that considerable interest in presented by the possibility, in certain cases, of designating some spore form or other spore by the name of a genus of sporangium or of a genus, the genotype of which is the whole plant; but from the point of view of stratigraphy it is of great importance whether we are dealing with a fossil sporangium or a spore structure which can be related to a sporangium genus.

5. So far research has been conducted within the framework of a definite stratigraphic level, the megaflora of which is well known, and certain spore and pollen structures may be linked with this megaflora. But in most cases, for all practical purposes we must deal with the stratigraphy of poorly studied deposits. That is why we must use particular designations for the pollen and spores discovered.

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[1] Znacheniye taksonomii spor dlya stratigrafii.

[2] A brief outline of the report by Prof. R. Potonie, "Die Beziehungen der Sporentaxonomie zur Stratigaphie," at the First International Congress on the Petrology of Coal, held at Heerlen (Holland) in September, 1958.

6. In working precise stratigraphic studies, it is impossible to do without pure species of organs and structures. They are often applicable even in cases when the botanists may consider that he no longer needs them.

7. An example of a certain genus and species of spore is one found at a particular stratigraphic and regional point which may serve as a point of departure for the stratigraphic research. Thus in no case should we restrict ourselves to only one criterion of the similarity between the fossil species and the spores of any other plant found in fossilized condition at other points. The presence of a spore structure of a definite stratigraphic level does not mean that the actual mother plant is also there.

8. It is quite clear that correct stratigraphy can be established on the basis of the study of dispersed sporés, provided the identifications are reasonably precise.

The necssary references for precise identifications and names are given in the International Code of Botanical Nomenclature, 1956. If we take these references as a guide in naming genera and species of spores, there will be no chance of any errors, however small. It is not very difficult to determine which systematic categories (taxons) are valid and which are not. Here it is particularly important to establish a particular type for the taxon. This refers not only to the genera of "complete plants," but also to those of organs and structures. Dispersed spores should also be related to genera of organs and forms.

There can be no clear-cut delineation between the genera of organs and structures. We are dealing with genera of organs in cases where it is possible to include them in a family in a natural system of classification.

Structure genera also include those whose family in the natural classification cannot be established (or has not yet been), since this frequently depends on the point of view of the investigator.

But in no circumstances should we restrict scientific study to a rigid framework. For example, not all genera of structures can be considered as artificial genera; it would be more to the point to call them morphographical genera. Many genera of structures (morphographical genera) may become organs (morphological genera) on further investigation, while others will evidently remain structural genera forever.

As pointed out above, the ultimate aim of a study of dispersed spores is to include as many genera of spores as possible in a natural system of classification of plants. But since in the majority of cases this has not so far been possible, we are placing them in a morphographical sequence in which, for purposes of clarity, the genus of the organ is also included. The units of this morphographical sequence, above the genus level (turma), do not conform to the international code and, in particular, to the method of types, like the units of the natural (morphological) system below the rank of order.

The first condition for accuracy in detailed stratigraphic subdivision of deposits by their spores is careful paleontological treatment of the dispersed spores. Certain species of spores must be recorded by photograpy, drawing and description (diagnosis).

In describing the structure of spores it is essential to abide by de Condol's requirements used in all branches of botany, i.e., as far as possible to use uniform "descriptive nomenclature" based on the rules of primacy.

In many cases it is just as important to draw the spores as to photograph them, since they are a sort of graphic portrayal of a verbal description, and despite the fact that drawings often contain elements of what the observer "seems to see," they should not be disregarded. But all the characteristic features of the structure in the drawing must also be clearly mentioned in the description.

Preparations for photographs must as far as possible be limited to points accessible to a large number of investigators. The International Code recommends that the place where the preparations are kept should be indicated in the actual published work (Recommendation PB 6 E).

When photographs of new species are published, it is desirable to indicate which copy has been regarded as the holotype of this species (Code PB 6 E) and where its locus typicus is to be found. In dubious cases it is not the author's description which is important in determining the species, but the external appearance of the holotype, so that the point where the specimen is found is of exceptional importance.

Type specimens of species whose stratigraphic position has been firmly established should be particularly carefully kept, since if their definition and description become obsolete with time, there will be a need to return to them. If the holotype of any species is lost, a neotype can be published, as far as possible from among the former loci typicii. Examples which correspond exactly to the holotype (or neotype), in a morphographical, stratigraphic and regional respect, are called cotypes. Since in most cases it is impossible to

compare the holotypes directly in solving stratigraphic problems, it is advisable to have a collection of cotypes in one's possession. Correlation of stratigraphic subdivisions of far-off territories is only possible if the above-mentioned requirements are observed.

In cases when the identification of the structures found in the deposits with an earlier established genus or species involves great difficulties, it is advisable in the interests of stratigraphy to make a separate description of this structure and give it a name. This procedure is customary in paleobotany, as set forth in the International Code (Code RB1, Note 1).

In the interests of stratigraphy, dispersed spores should not be confused with the spores found in sporangia. The spores extracted from sporangia cannot always be compared with morphologically similar dispersed spores. In certain cases the name of the dispersed spores is more comprehensive than the name of the sporangia.

If the investigator jumps to conclusions, the relegation of the dispersed spores to a sporangium genus may lead to erroneous stratigraphic conclusions. For example, it is sometimes necessary in stratigraphy to use different terms for spores which differ externally, but which perhaps belong to the same plant species. An example of this could be the simultaneous occurrence of megaspores and microspores. Generally speaking, we know very little about the relationship between megaspores and microspores. Nor do we know the degree of variation within various species of such spores. Consequently, it is quite possible that in different cases we will assign the same species to a larger or smaller number of plant species.

It is an interesting fact that in a single sporangium one can find spores at different stages of maturity. It the same spores had been found as dispersed spores (sporae dispersae), there is no doubt that they would have been given different names.

But spores usually emerge from the sporangium in a fully mature state. Thus the spores which become "dispersed spores" have usually reached the same degree of maturity. But another fact must be taken into account here: the immature spores from one plant species may be similar in appearance to the mature ones from another species. Hence in identifying dispersed spores one should not be hasty, and one must try to relate the dispersed spores to a species of sporangium, keeping in mind the varying degrees of maturity.

To ensure maximum caution in drawing scientific conclusions, the International Code permits the adoption of nomenclature for genus and species names in different degrees of preservation.

Despite the fact that, in dealing with fossil material, it may always be presumed that certain species of dispersed spore organs belong to certain species of mother plants, this cannot always be proved with complete authenticity.

If we always identified certain species of spores with the known spores from fossilized plants, we should have to assert that wherever the former were found, the plants to which we relate them also grew. Cases have been known, however, where such comparisons have resulted in an extension of the stratigraphic limits within which the alleged mother plant is found without valid reason.

Thus it should always be kept in mind that, apart from the alleged mother plant, there may be other species which have formed, or at least other spores which in the given case cannot be differentiated clearly in their existing state of preservation.

ARGON METHOD OF DETERMINING THE ABSOLUTE AGE OF ROCKS AND MINERALS[3]

by

A.S. Shur

The argon method of determining the absolute age of rocks and minerals has become firmly established and is in wide use, both in the Soviet Union and abroad.

At the present time there are two experimental methods of quantitative calculation of radiogenic argon: 1) the mass-spectrometer method, and 2) the volumetric method. A considerable number of investigators determine Ar by the volumetric method. The latter has been carefully worked out and is fairly reliable, but a major drawback is its low productivity. This can be compensated to some extent by increasing the number of experimental units working in parallel, independently of each other.

We have designed a device for the volumetric calculation of radiogenic argon, based on the well-known principle of so-called internal heating. The chief merit of this apparatus is its increased productivity; it can

[3] K argonovoy metodike opredeleniya absolyutnogo vozrasta gornykh porod i mineralov.

make six to twelve calculations per week (i.e., one or two per day). This output makes it superior to the second device which we use, which employs external heating to melt the specimen. The small quartz consumption can also be considered one of its advantages.

As can be seen from the diagram, the design of the unit makes it possible to conduct 6 experiments simultaneously. The specimen, 5 to 8 grams in weight, and ground down to a grain size of 0.5 to 1 millimeter in diameter, is poured into a quartz ampoule (11, Fig. 1), into which a heating spiral made of alloy No. 2, or nichrome, 0.5 to 0.7 millimeter in diameter, is then inserted. The ampoule is placed in the reactor (2). The dimensions of the ampoules are: 8 to 10 centimeters in length and 9 to 12 millimeters in diameter. One quartz ampoule and a spiral are used up in each experiment. There must be a gap between the spiral and the ampoule of approximately 0.3 to 0.5 millimeter; otherwise, when the spiral heats up and expands, the ampoule bursts. The molybdenum-glass reactor is 30 centimeters high and has a diameter of 7.5 centimeters: at the top is a slide through which the specimen is loaded. Electric leads made of molybdenum wire, 1.2 millimeters thick, are soldered to the slide stopper (1). Heating is continued until the sample is sintered or melts, and it is particularly important here that the slide should stay cold. The heating temperature can easily be controlled by an LATR-1 automatic transformer. The temperature is measured with a platino-rhodium thermocouple, introduced into the ampoule through the slide stopper of the reactor, for which a small additional slide with a stopper made of ordinary glass is made in the stopper of the reactor. The platino-rhodium thermocouple is soldered to this stopper. To protect the thermocouple from the aggressive action of the fused mineral, the hot end of the thermocouple is put into a fine quartz tube, and direct contact between the thermocouple and the fused mass of the specimen is thereby avoided.

The argon was usually purified by means of liquid air, cupric oxide and metallic calcium simultaneously in all samples. The U-shaped tube made of heat-resistant glass (4) with a red strip) is filled with cupric

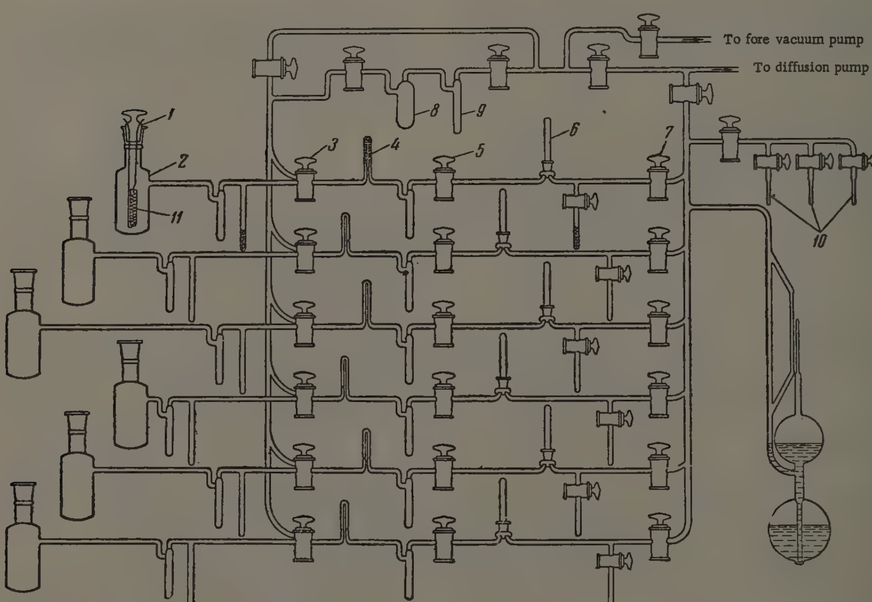

FIGURE 1. Diagram showing unit for volumetric measurement of radiogenic argon:

1 -- slide; 2 -- reactor; 3 -- three-way faucet; 4 -- U-shaped tube with cupric oxide; 5 -- two-way faucet; 6 -- test tube with calcium; 7 -- two-way faucet; 8 -- trap with caustic potash; 9 -- trap for liquid air; 10 -- removable ampoules with activated carbon for mass-spectrometer checking of the argon; 11 -- quartz ampoule for the melted specimen.

oxide and soldered to the system, as shown in Figure 1. Periodic regeneration of the cupric oxide does not create any difficulties. For the calcium we use the quartz tube (6), 15 centimeters long and 2 cm in diameter, with a slide joining it to the whole system. The calcium is loaded into the tube and the spent calcium extracted from it quite easily, since the slide of this tube is in picein.

All six specimens are also pumped out simultaneously, except for the measurement of the radiogenic argon, which is carried out separately with a McLeod gauge. The capillary tube of this gauge, 0.57 millimeters in diameter, provides a high degree of accuracy and sensitivity in the measurement.

Working conditions. The gases and specimens undergoing the test are desorbed at 200° to 250°. The moisture given off at this temperature is absorbed by caustic potash (8) and liquid air (9), thereby excluding the possibility of water vapor getting into the vacuum pump. As soon as the vacuum adhesion point is attained (10^{-6} mm Hg), the working part of the system is disconnected from the evacuation communication, and the samples in the reactors are heated to the sintering or melting point, during which the water and gases given off are consistently combined with liquid nitrogen and activated carbon by means of traps, the activated carbon trap is also immersed in liquid nitrogen. Thus during the melting there are no free gases in the reactors, and consequently neither are there any convective currents from these gases, through which the reactors might heat up. It should be pointed out that under these circumstances the reactors do heat up to a slight extent, while their slides do not heat up at all. The latter point is important, since it precludes the possibility of argon from the air entering the system through the reactor slide. The melting continues for 30 or 40 minutes. This time can be shortened, but this is not advisable, since over a shorter period the radiogenic argon may not have time to be completely separated from the slide. On the other hand, we attempted to extend the heating time to 1 or 1-1/2 hours, but even then the reactor slides did not heat up, but remained as before at room temperature. This fact convinced us that the design elements of the described method were chosen correctly.

As soon as the melting has finished and the reactors have been allowed to cool down to room temperature (the cooling lasts 15 to 20 minutes, the gases from the activated carbon are desorbed and passed over cupric oxide, after which they are purified with Ca according to the conventional methods. All these stages are included in the system and shown in the diagram.

The required temperatures for the experiments are set and maintained by thermocouples made of chromel-copel for calcium and cupric oxide, and by copper-constantan thermocouples for the activated carbon.

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IN MEMORY OF NIKOLAY NIKOLAYEVICH SLAVYANOV[1]

June 13 of this year was the eighty-first anniversary of the birth of the oldest Soviet hydrogeologist and corresponding member of the USSR Academy of Sciences, Nikolay Nikolayevich Slavyanov, who died on October 16, 1958. He was born in 1878, in the Vyatka Guberniya (now the Udmurt ASSR), into the family of a mining engineer and metallurgist, Nikolay Gavrilovich Slavyanov, who is well known in the history of technology as the inventor of electric welding.

Even before graduating from the Mining Institute in 1908, Nikolay Nikolayevich had begun working in the Geological Committee. Here, beginning in 1907, he passed through the classical mapping school under the guidance of such eminent Russian geologists as L. I. Lutugin, P. I. Stepanov and A. P. Gerasimov, in making a fairly large-scale survey of the Donets coal basin.

In 1912, Nikolay Nikolayevich began to be occupied mainly in geological surveying and organizing the damming of ground waters. His position in the Geological Committee was accordingly changed: in 1924 he became Secretary of the Hydrogeological section of the Committee, and in 1928 the head of its Ground Water Laboratory.

In 1912 Slavyanov was commissioned by the Geological Committee to study the ground waters of the Caucasus beginning with Zheleznovodsk, where among other things he derived and dammed a spring which was later named after him. This world-famous spring is still the source of the so-called Slavyanov mineral waters. His investigations were then transferred to the Kumogorsk and Kuban' ground waters, and after the Great October Socialist Revolution, in 1921, to the Matsesta, Psekupsk, Yeysk, Zaporozhian, Ossetian and Georgian ground waters. In 1930, he expanded the range of his investigations: he journeyed to the Urals, Altay and Tien Shan ground water springs: visited the ground water springs of Karelia and the Leningrad Oblast'; organized and acted as consultant in hydro-geological work on supplying drinking water to such towns as Anap, Novorossiisk, Sestroretsk, Baku and a number of towns in the Donets Basin, and the mineral-water supply for a number of health resorts.

Thus by 1930 Nikolay Nikolayevich was already known as a great expert on ground waters.

In 1935 he was awarded the degree of Candidate and in 1942 the degree of Doctor of Sciences, without having to defend his dissertation, on the recommendation of Academicians V. I. Vernadskiy, V. A. Obruchev and P. I. Stepanov; in 1946 he was elected a corresponding member of the AN SSSR.

In studying the ground waters of our country for 45 years (1912-1957), Nikolay Nikolayevich made great contributions to the theory of their formation and the laws governing their distribution, particularly in the Caucasus, and also a great contribution to determining the mineral water sources for the resorts of our country. In this branch of science he established that alliance between hydrogeologists and bath-and-health-resort specialists, which was so urgently required by the construction of health resorts in our country, particularly from the 1930's onwards. He played a great part in the hydrogeological education of doctors, the balneological education of hydrogeologists, and also in the conservation of the USSR's ground waters; he contributed much work to both the technical and the legal aspects of water conservation.

Nikolay Nikolayevich's activity was associated with a wide range of organizations: the Caucasus Ground Water Administration, the Kuban' Health-Resort Administration, the Central Institute of Health Resorts, and the Pyatigorsk Balneological Institute. He was a member of a number of scientific societies: the Balneological Society of Pyatigorsk, the Medical Society of Zheleznovodsk, the International Society of Medicinal Hydrology, the

[1]Pamyati Nikolaya Nikolayevicha Slavyanova.

scientific councils of the Health Resort Council of the Ministry of Health of the USSR, the Medical Council of the Ministry of Health of the RSFSR, and also other societies and learned councils specializing in geology. His work in all the mentioned institutions, societies and councils was carried out with close cooperation between the representatives of both geological and medical sciences.

Nikolay Nikolayevich combined his many-sided scientific and social activities with a great amount of teaching work. In 1910 he was giving lectures on geology and astronomy and the Shlissel'burg Evening School for Workers, which was later renamed the People's University, and in 1917 he was lecturing on the geology of mineral ground waters in balneological courses for doctors from the All-Russian Land Alliance in Pyatigorsk; from 1918-1921 he was lecturing on geology and crystallography at the natural science and medical departments of the People's University of Pyatigorsk; in 1919 he became a lecturer in the geology department at the North Caucasian Polytechnical Institute, and secretary of the mining department as well; in 1920-1922 he was lecturer in "Encyclopedia of Mining and Geology" at the Pyatigorsk Workers Polytechnic, where he also acted as Dean of the Prospecting Faculty. In 1922, he taught the geology of ground waters in balneological courses for doctors at the Pyatigorsk Balneological Institute. In 1929 he went to Leningrad, where he was first a tutor, then lecturer and finally professor of hydrogeology in the geographical faculty of Leningrad University, and from 1930 through 1934 he was a professor at the Leningrad Mining Institute. There he was the organizer and first dean of the hydrogeological faculty and head of the ground water department.

Moving to Moscow together with the Academy of Sciences, he was given charge of the hydrogeological department of the Moscow Hydrometeorological Institute (from 1935-1940), and from 1935-1939 was at the same time a professor at the Moscow Prospecting Institute of Geology, and in 1940 a professor in the geology department of the geology and soil faculty at Moscow University. From 1941 to 1942 he was a professor in the Moscow Institute of Transportation Engineers. During the months of enforced evacuation in World War II, from 1942-43 Slavyanov was professor and head of the department of geology at the Khabarovsk Transport Engineers Institute.

During his long years of teaching Nikolay Nikolayevich tirelessly educated groups of highly qualified specialists in geology, hydrogeology and geochemistry. A characteristic feature of his teaching was that he always urged young people to combine theory and practice in their work. His own life and work were the very embodiment of this unity. Another feature of his teaching was that water as an object of study was never divorced from the surrounding geological medium, and hydrogeology was always regarded as an inseparable part of the science of geology. His is a hallmark of the classical school of Russian geology of which he himself was a member in his earlier years.

Nikolay Nikolayevich approached the study of underground waters as a geologist, and it was precisely this that gave him his originality in solving a great number of problems connected with the study and damming of ground waters, and the methods and techniques of prospecting for both mineral and underground waters. He was the first person in actual practice to study ground waters as part of the study of deposition, rather than from the point of view of springs. This led him to devise technical methods of prospecting which were at first considered impractical, such as washing the shafts when drilling for ground waters, experimental pumping, and so on.

On the other hand, in his hydrogeological research he also dealt with purely geological problems concerning regional geology and tectonics, mainly in the Caucasus and the Donets Basin.

Having labored half a century in the study of ground waters, Nikolay Nikolayevich became one of the founders of the alliance of hydrogeologista and hydrochemists, now so productive, which produced a new science – hydrogeochemistry. Even as early as 1930 N. N. Slavyanov was often consulted on problems involving the study and utilization of gas deposits, particularly of helium. Thus in 1930, when a new branch of science, gas geology, was born in the Soviet Union, Nikolay Nikolayevich was a leading figure in it.

Of great importance, too are his studies of principles in interpreting the chemical composition of underground waters, the graphic depiction of chemical analyses of water and its evaluation from the industrial and economic point of view. He was one of the first hydrogeologists to point out the need to use an equivalent form in depicting the chemical analysis of water. This form was widely used in the study of oil, mineral and underground waters as a whole. He was the first to raise this question at the Second Hydrological Congress in 1928. The method has now been fully developed, but at that time, thirty years ago, it was a discovery. Of great importance is a paper written by Nikolay Nikolayevich entitled "Equivalent Form for Expressing Water analyses and its Application," published in 1929 and republished in 1932, since it was one of the first important links in the scientific

chain leading to the creation of hydrogeochemistry.

Nikolay Nikolayevich was the author of approximately 110 published works, including a number of translated works edited by him.

Among his works are "Ground Waters of the Northern Caucasus," "Ground Waters of Karelia," "Ground Waters of Central Asia," "Ground waters of the Azov-Chernomorsk District," "History of the Zheleznovodsk Mineral Springs and the Zheleznovodsk Health Resort."

In 1933 N. N. Slavyanov joined the Geological Institute, which is part of the Academy of Sciences of the USSR. There he spent some time as the scientific head of the hydrogeological sections of the Far Eastern Composite Expedition along the Baykal-Amur Highway. In 1940, on the initiative of Academician V. I. Vernadskiy, a permanent Ground Waters Commission of the USSR Academy of Sciences was established, and Nikolay Nikolayevich was appointed Deputy Chairman of the Commission. In 1944, when the Hydrogeological Laboratory of the USSR Academy of Sciences was established, the Commission's functions were transferred to the Laboratory; Nikolay Nikolayevich was therefore transferred to the staff of the Laboratory and took up the post of Deputy Director. At the beginning of 1947 he became Director of the Laboratory and worked for 10 years at this post.

Many hydrogeologists, who have now become great specialists, candidates and Doctors of Sciences, have not yet fully realized and appreciated the part played by Nikolay Nikolayevich in their education and training as scientists, in their scientific outlook and their professional work. This appreciation will come later.

Throughout the whole of his life Nikolay Nikolayevich showed his regard for the younger generation and for molding young people in the spirit of love for science, one's country, the working people, and in the spirit of dilligence and modesty. He was himself an example of this diligence, modesty, attentive and considerate attitude toward people, honesty and integrity.

His image will remain in our memories as an inspiration to everything that is bright, good and pure in life.

D. I. Gordeyev, T. P. Afanas'yev
F. A. Makarenko

REVIEWS AND DISCUSSIONS

IN DEFENSE OF GEOLOGICAL SCIENCE [1, 2]

by

V. V. Belousov

The book being reviewed is a striking example of a specific type of literature in the field of general problems of geophysics and geotectonics, which of late has unfortunately become quite abundant in foreign countries. This literature is compiled by persons versed in mathematics and geophysics, but completely unversed in geology, which, however, does not keep them from thinking that they have the right to consider problems of the development of the earth's crust, i. e., problems which are basically geological ones.

No one would ever think of immersing himself in specialized mathematical problems without the proper training, whereas excursions into geology without the relevant knowledge are considered quite acceptable. This reviewer hastens to state that he is entirely in favor of using physical, mathematical and other precision methods in geology, and what is more, in the alliance of geology, for example, and physics and geophysics he sees one of the most important means toward further progress in the geological sciences. This alliance, however, is clearly only of use if it is based on equally qualified use of data and results from all the sciences involved. Otherwise such attempts become absurd.

In his preface the author warns readers that he has no firm opinions in the field of geodynamics, that he is an agnostic in this particular field, and that his book is a combination of different ideas and points of view. We cannot help agreeing. What is difficult to understand is why was it necessary to write the book at all, with this kind of intellectual equipment.

The first chapter sets forth geological data. The account is completely unsatisfactory from any point of view. One is amazed by the chaos in the succession of the account contained in these pages. First the author says a little about rocks and geologic time, then something about paleoclimatic data in the light of views of the movement of the poles, and then about the geometry of continents with a definite tendency to put the idea of continental drift into the reader's mind. The structure of folded regions is dealt with extremely primitively. At the same time, the author concentrates on certain forced geometrical arguments on the position of mountain chains and island arcs.

Having thus skipped through the major problems (taken at random), the author decides to discuss elementary structural forms — faults and folds. The chapter ends in a quite extraordinary way; on pages 24 to 29 we find the following order of examination: meteor impact craters, boudinage, domes, volcanos local uplifts in Fennoscandia.

The second chapter sets forth "Geophysical data on the earth" (it is left to the author's conscience whether or not geophysical data can deal with anything else except the earth!). The author knows these data. The account is elementary and very brief.

Chapter III deals with the mechanics of deformation. There is sufficient mathematics here, but almost none of the entire account has any bearing whatsoever on the problems of geodynamics examined later. It is simply a short chapter from any textbook on the theory of elasticity and plasticity. The author does not know which aspects of the theory are needed by the geologist, or how to discuss them. It is only in the last section of the chapter that mention is made of the state of matter inside the earth, and here he mixes elementary information with conjectures which

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[1] V zashchitu geologicheskoy nauki.

[2] A. E. Scheidegger, Principles of Geodynamics, Springer-Verlag, Berlin-Goettingen-Heidelberg, 1958.

are only applicable if a whole number of unproved assumptions are correct. This is the typical approach of a mathematician who does not understand the specific nature of a natural discipline and who is trying to foist upon nature conditions which are entirely alien to it.

I cannot judge the contents of the special chapter on the "Effect of the Earth's Rotation," but it is very characteristic that the question of whether movement of the poles has occurred is solved by the author, not on the basis of an analysis of historical geologic data, but from mathematical considerations based on completely arbitrary judgements of the viscosity of the earth's crust, and so on.

The fifth chapter is devoted to the continents and the oceans. Discussing the origin of the earth, the author fails to mention the latest hypotheses of the accumulation of the earth from a cloud of cold particles; he then goes on to put forward in a dispassionately way different views of the history of the continents and the oceans, without making any attempt to evaluate them from the standpoint of geological data. This makes the reader suspect that science just does not have possibilities of making such an evaluation.

Chapter VI is the main one in the book, entitled "Orogenesis." It need hardly be said that it does not contain any laws at all governing the structure and development of folded zones, as established by geology (geotectonics). It merely lists hypotheses, which the author analyzes mathematically to some extent, but which cannot be examined from a geological point of view at all. It does not take very long to see that the science of "geology" does not exist for the author. But, actually, what right has the author to try to give untrained readers the impression that the science of the earth is just a pile of unproved fabrications and hypotheses that are thought up for some reason or other and ultimately unverifiable?

The arguments on the dynamics of faulting and folding contained in chapter VII bear little relation on geological reality.

In the last chapter the author describes the phenomena characterized above in speaking of the end of the first chapter.

To obtain some idea of the standard of this chapter, we need only to look at the section entitled "Domes." Here the author confuses two quite different types of domes — diapir domes, and uplifts formed by the lateral bending of strata due to vertically applied forces. To be more accurate, he simily knows nothing of the existence of the second kind, although they are extremely common on all platforms, and in the South American platform in particular are a reservoir of great oil reserves.

The author is probably not a bad specialist in his own field, but he has made a great mistake in dealing with questions far beyond his competence and interests. What he has written is a caricature of geology — a science which in the author's opinion, knows nothing, can do nothing and perhaps should not exist at all.

REVIEW OF "METHODS OF STUDYING SEDIMENTARY ROCKS" (VOLS. 1 AND 2)[3,4]

by

G. I. Teodorovich

The preface to the book reviewed here says that in dealing with disputed questions the editors have in many instances only offered readers one point of view, "as being the only true viewpoint," without going into others or criticizing these "incorrect" conceptions. It is said that this approach has given a certain subjective flavor to the book, but that the latter has nevertheless thereby acquired a certain "physiognomy" and "a certain unity" (vol. 1, page 5). We cannot agree with this assertion, since every guide or handbook should represent objectively the fundamental existing methodological and genetic opinions.

The introduction (by N. N. Strakhov), containing in vol. 1, is brief and not entirely objective, but nevertheless gives a general picture of the sedimentary process. We cannot agree with the quotation of facies profiles of authigenic sedimentary formations in a humic climate from the Devonian up to the present time. The sedimentation conditions could not in actual fact have been so constant. This does not only apply to sedimentary rocks, but also to formations of extrusive-sedimentary origin.

Appropriate space is given in the introduction to data on the formation of the carbonates of Ca, Mg, and Na, sulphates and chlorides. On page 15 there is a drawing, Fig. 5, given without reservations, which contains a general diagram of the precipitation of carbonates, and halogenesis in present-day continental lakes of the dry zone as a whole. But this diagram is not universally applicable and

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[3] O Knige "metody izucheniya osadochnykh porod" (tt. 1 i 2).

[4] Gosgeoltekhizdat, 1957.

cannot be applied in its present form to the study of ancient sedimentary rocks (pre-cambrian, Paleozoic and so on), which were deposited at different geological times with sharply differing pCO_2 and temperature values, and with a different salinity in the seas in ancient times.

The diagenesis of sediments as a process divided into stages of the formation of oxidizing and reducing minerals and the state of redistribution of the matter and formation of concretions, is dealt with extremely sketchily. The study of concretions (by A. V. Makedonov and others) shows that concretions form during the earlier, and not the later diagenesis. The description of epigenesis, early metamorphism and the problems of sedimentary petrology gives no grounds for complaint, except that it is too brief.

The first part of the first volume, "First Observations of Sedimentary Rocks and Sedimentary Minerals" is written interestingly and is fairly thorough. This applies to Chapters I, II IV and V, so that we shall make only a few comments on this part of the work. Chapter I, "General Observations of Sedimentary Rock Sections," is particularly well written. Chapter 2, on "Field Observations on the Color of Sedimentary Rocks, their Composition and Weathering" is also a good one.

Chapter III, on the structures and textures of sedimentary rocks, is unsatisfactory. Its scope is insufficient, hieroglyphs and fucoids are not considered sufficiently, no reference is made to stratitextures and lapidotextures, nor is there a description of natural stylolite surfaces and "cone in cone" formations. The genetic significance of different types of cross bedding is treated too easily on the basis of vertical sections which is unconvincing without careful consideration of the areal distribution of the relevant types of deposits, while in the case of basin conditions (sea and lake), cross bedding does not provide any simple interpretation of the genetic types of deposits at all.

Chapter IV, "Observations of Organic Remains," will be extremely useful to the beginning sedimentary petrologist and to geologists generally.

Chapter V on "Observations of Concretions" is very brief; it lacks a description of the transitional forms between concretions and lenses ("perforated lenses of concretionary origin") and of the relevant scientific literature. On the other hand, certain references sound naïve; for example, "phosphorite concretions according to G. I. Bushinskiy, mainly characterize marine transgressive sediments" (page 137). It is well known that this feature was noted much earlier and formulated by A. D. Arkhangel'skiy and other lithologists.

Chapter VI, "Elements of Field Facies Analysis," as difficult from the subject, as one may see from the title itself, is set forth rather well by the author, but has a too clearly marked slant towards the study of coal-bearing deposits. It would be a good thing to expand this chapter and elucidate facies analysis with specific examples from other types of deposits.

In the second part of the first volume, the author deals with laboratory methods in the mineralogic and petrographic study of sedimentary rocks. The introduction to this part is passable; it gives in condensed form a general picture of laboratory research.

The authors of Chapter I of the second volume have set themselves a difficult task — to describe in 57 pages the study of the mineral composition of sedimentary rocks and organic remains in thin sections; they have had to limit themselves to the description and diagnosis of only the chief clastic and authigenic sedimentary minerals, as well as a brief description of limestones, silicates, phosphates and carbonized organic remains. The description of the authigenic minerals is unnecessarily brief, and does not include the oxides and hydroxides of iron, manganese, aluminum and copper,[5] which is unacceptable; nor is there any reference to iron phosphates, dissolved salts and certain other groups of minerals. The bibliography on this section is one-sided.

Chapter II of part 2, "Study of the Structures and Textures of Sedimentary Rocks in Thin Sections and Polished Sections," describes in too much detail (considering the small scope of the chapter) the form of authigenic minerals and their genetic importance, and, conversely, gives insufficient space to the various types of cement (their structure, composition and origin) and the relationship between clastic grains and the cement.

Chapter III of the second part, "Elements of Stage Analysis of Sedimentary Rocks on the Basis of Microscope Investigation" is one-sided: it is practically all based on recent work by N. M. Strakhov (1954), G. I. Bushinskiy

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[5]No description of the sedimentary minerals in the group of oxides and hydroxides of manganese and copper, and their soluble salts, is given in either the first or the second volume of the "Handbook." The enumeration of the iron oxides and hydroxides in Chapter II of the fourth part of the second volume, and the extremely brief description of the aluminum hydroxides in the same place, naturally do not affect the valuation of this chapter.

(1954), and the authors of the chapter (or similar work by these authors over the years 1951-1955), as though there had been no genetic analysis in sedimentary petrology before their own research. The recrystallization of limestones, dolomitization, silicification and dedolomitization are described too primatively. The actual processes are not dealt with, or else considered too briefly and inadequately. There is absolutely no mention of the well-known work of M. E. Noinskiy on the Carboniferous and Permian deposits of Samarskaya Luka, or B. P. Krotov's work on the Permian dolomites in the environs of Kazan, in which he considers the causes of dedolomitization. The diagenetic transformations of ferruginous minerals are dealt with from the standpoint of the artificial three-stage diagenetic scheme devised by N. M. Strakhov (the stages of oxidizing and reducing mineral formations and the concretion-forming stage).

Generally speaking, Chapter III produces a strange impression, since the bulk of it is concerned with two examples of "stage" analysis — the carbonates of the carboniferous rocks from the Russian platform (pp. 252 to 266), and the terrigenous rocks of the Mesozoic and Paleozoic from the Western Verkhoyanye (pp. 266 to 283). Both the examples are described in far too much detail. The description of the Russian platform carboniferous is not good, since it merely deals with the subject petrographically and does not discuss the processes seriously; it would have been more to the point in the case of platform conditions to give several diversified examples of "stage" analysis. The second example — the Mesozoic and Paleozoic from the Western Verkhoyanye — is essentially a detailed analysis of an interesting particular case, which should have been published in a scientific journal, and not in the "Handbook." This would have made it possible to expand several sections of the book which are now clearly overcondensed.

Generally speaking, it would have been more to the point to include a number of examples of stage analysis for a wide variety of deposits; it is hardly possible to give directions for all particular cases of lithologic analysis, which depends on the age of the deposits, on their location, and on the geologic (primarily tectonic) history of each specific region. It would have been better to include material on epigenesis and early metamorphism in condensed form in the introduction to the first volume. Finally, it is not clear which material has been used as the basis for the main stages in the alteration of carbonate rocks (page 265), set forth for all carbonate rock, regardless of their geological position in time and space.

Chapter VI in the second part, "Laboratory Study of the Physical Properties of Rocks" hardly needs any comment, except to mention the omission of methods of studying and characterizing carbonate oil and gas reservoirs, although such methods, devised in the USSR, have been adopted by petrographers and oil geologists in the USA.

Chapter V, "Granulometric Analysis of Unconsolidated and Poorly-Cemented Sedimentary Rocks," Chapter VI, "Study of the Minerals in Grains of Sand and Silt Dimensions," Chapter VII, "Principles of the Study of Finely Dispersed Minerals" and Chapter VIII, "Identification and Quantitative Determination of the Minerals in Sedimentary Rocks, using Thermal Analysis," are among the most interesting parts of the first volume.

One is surprised by the chief editor's note to Chapter V, in which he says that the genetic ("dynamic," in application) diagram by L. B. Rukhin is unnecessary, since "in the absence of other reliable criteria, dynamic analysis alone is not in a position to determine this medium (page 341). It is well known, however, that Rukhin's diagram is used in lithologic and geologic practice and that in the geological and mineralogical sciences a definitive solution by any one method is rare — it usually requires several methods.

Chapters VII and VIII in the second part, which describe the latest equipment, working methods and analysis of results, are embellishment of the first volume. Together with Chapter I they are the best in this volume.

The idea of singling out a single chapter (9) for the basic concepts of statistical processing of factual data is a good one and quite in order.

The first volume of "Methods of Studying Sedimentary Rocks" is well illustrated, mainly with microphotographs, although of course with the above-mentioned disproportions in certain chapters.

Summing up the reactions to the first volume of "Methods of Studying Sedimentary Rocks," it should be stressed that the book is a useful beginning, and as a whole is not too bad in its present form, although it has a number of substantial defects. If our comments are taken into account when the work is published in a new edition, it can become still more valuable and important for geologists and beginning sedimentary petrologists.

II.

Let us now turn to the second volume of this book (1957), which contains Parts 3, 4, 5

and 6. The third part of the work, "Chemical Study of Rocks" causes some surprise, since it sets forth only the methods of chemical analysis, and only those for carbonates at that. From our point of view, only one chapter (Chapter I, "Chemical Study of Sedimentary Rocks and Principles of Systematic Analysis"), which is written concisely and clearly, should be left in.

Chapter II, "Chemical Analysis of Carbonate Rocks" should not have been included at all in the book, since sedimentary rocks and ores cannot be reduced solely to carbonates, and, also because the book is a reference work for geological surveyors and geologists in general, and not for chemists.

In view of the abundance in nature and practical importance of clays, Chapter III in the second volume, "Determination of the Form of Certain Elements and Analysis of Colloidal Clay Fractions" is quite suitable for this handbook.

The special description of the methods of determining minor elements (Chapter IV of the second volume) is superfluous. Chapters II, IV, etc. should have been combined, supplemented with chemical methods of investigating other rocks, and published as a separate book.

Chapter V, "Polarographic Determination of Heavy Metals in Rocks," as one which sets forth a particular method of determining matter which can be electrolitically oxidized and reduced, is rightly included in the handbook, but should be combined with material somewhat more extensive in the sense of a "collection of elements," and narrower from the point of view of purely laboratory working methods. In particular, iron and manganese, which are the basic indicators of the oxidizing-reducing potential, are only given two pages, while Cu, Ni, Co, Zn and Cd get eleven pages. Such material on chemical methods could well make up a separate book, as indicated above.

Chapter VI in part three, "Spectrum Analysis," is written interestingly and succinctly; it should be expanded by introducing examples of spectrum analysis in the mineralogy of sedimentary rocks.

Chapter VII, "Methods of Determining the pH and Eh Values in Sedimentary Rocks," is quite suitable for this handbook, and is clearly written. The section of the chapter on the use of Eh and pH values in geological practice could well be expanded and deal at the same time not only with the stability of minerals over certain pH and Eh value ranges, but also with the corrections necessary for using such data from non-weathered sedimentary rocks in reconstructing the conditions under which diagenesis of the sediments occurred.

Chapter VIII "Study of Organic Matter Dispersed in Sedimentary Rocks" is presented in detail and meets the needs of most geologists (particularly petroleum, coal and gas geologists) for an explanation of the nature of disseminated organic matter in various complexes of a section in the territories under study.

Chapter IX, "Chemical Study of Sedimentary Rocks for Genetic Purposes and Correlation," is not written with the same objectivity throughout. Part of the chapter dealing with the salinity of ancient bodies of water is generally speaking well written, but it omits to mention both in the text and in the bibliography the method of determining the salinity of fossil basins proposed by Yurkevich and later published (1956).

In the section of Chapter IX on "General Preconditions for Reconstructing the pH and Eh Values in the Waters and in the Sediments of Ancient Seas," N. N. Strakhov includes a number of his own polemical assertions regarding geochemical facies as a whole, and on the oxidation-reduction potential section in particular. Ignoring the works I have published myself (1947, 1949, 1951, 1952, 1954 and 1956) in which I mentioned the lack of benthos in the oozes of the sulphide and sulphide-siderite facies and the impossibility of using the FeS+ content to determine the intensity of the oxidation-reduction potential in rocks, he attributes the opposite viewpoint to me and then proceeds to criticize it. As early as 1949, (Doklady AN SSSR, Vol. 69, No. 2) I pointed out that there are two sets of oxidation-reduction potential conditions in nature: multiple micro-oscillating and stable; in the latter case the upper film or layer of sediment is in the oxidizing zone, while beneath the oxidizing-reducing level all capable of entering into reactions is converted into sulfides (or sulfides and other higher oxidie compounds). Quoting examples of the second kind, and ignoring our references to the impossibility of establishing the type of profile of the oxidizing-reducing level from the FeS_2 content, Strakhov tries to deny the existence of geochemical facies with multiple oscillating oxidizing-reducing levels, for which I have always suggested merely a middle position. The point is not a vertical mixing of the waters, as described by Strakhov, but the stability of the effect of a particular factor.

The third section in Chapter IX, "Possibilities of Reconstructing the pH and Eh conditions in marine waters by geochemical methods" is written clearly, concisely and interestingly.

The fourth section, "Possibilities of determining the Oxidation-reduction Potential in Ancient Marine Deposits," replaces the geo-

chemical facies worked out earlier by L. V. Pustovalov (1933) and developed by G. I. Teodorovich (1947, 1949 and 1952), with geochemical environments (L. A. Gulyayeva, 1953, 1955), with regard to organic matter. These environments do not exhaust all the basic types of geochemical facies in the oxidation-reduction potential section; among them there are no proper siderite facies or glauconite facies (L. A. Gulyayeva has 4 environments instead of the 6 mineral-geochemical facies in the oxidation-reduction section). In 1954 (Doklady AN SSSR, Vol. 96, No. 3) and in 1955 (Soviet Geology, Collection 47) I pointed out that in classifying geochemical facies with respect to organic matter one had to use the same iron mineral indicators, but the additions to the mineralogical terms in this case change by ore degree of oxidizing-reducing intensity. Although in relation to iron compounds the given geochemical facies, for example of the lower and higher oxides of leptochlorite, is neutral as regards the oxidation-reduction profile (rH), in relation to the organic matter it is slightly oxidizing and so on.

Strakhov writes: "An idea of the oxidizing-reducing conditions in ancient sediments can only be obtained indirectly, by sludging the diagenetic minerals" (page 168). But this is exactly what I had done in ascertaining the geochemical facies with respect to the rH profile as early as 1946 and 1947 (MOIP Bulletin, geology section, No. 1). But on pages 169 to 170 of Section 4 there is a description in italics of the method of determining the oxidizing-reducing conditions in the sediment, according to N. M. Strankhov and E. S. Zalmanzon (1955), all the basic sets of conditions being derived from the minerals in accordance with our classification of geochemical facies of 1947 and 1954. Such a description of a theoretical matter in the "Handbook" cannot be considered suitable.

In the fifth section of Chapter IX, "Possibilities of Determining the pH value in Ancient Marine Sediments," Strakhov deals with the general question and makes an unfounded retreat with regard to the probable geochemical facies of Precambrian seas, which I cannot consider in this review.

In the sixth section, "Classification of Geochemical Facies" he tries to prove that our geochemical facies classification is invalid, in that we single out a smaller number of geochemical facies types than is found to be the case in intersecting a number of facies along the rH profile [6] and the pH profile [6], when by simply multiplying these numbers he gets 36 units to each of which he arbitrarily assigns the status of a facies. Typical mineral-indicators cannot be assigned in even a single case to each one unit of the geochemical facies system which I suggested. Hence the criticism of this system by Strakhov is unconvincing and hardly suitable for inclusion in a methodological handbook.

The seventh and eighth sections of Chapter IX are written fairly objectively and succinctly.

Part 4 of the work under consideration, "The Lithologic Study of Sedimentary Rocks and Sedimentary Minerals" consists of 6 chapters. We feel that the scope of these chapters should be expanded when the book is republished.

Chapter I of the fourth part, "The Study of Clastic and Argillaceous Rocks" is very small: it should have contained classifications of sandstones, siltstones and clays by others than L. B. Rukhin, described several new classifications of sandstones, and so on. It would have been better for this chapter to have been larger.

The footnote on page 189 is difficult to understand. It says: "Recently L. B. Rukhin (1956) has proposed that particles from 2 to 0.05 mm in size should be classed as sand particles." In the first edition of "Petrography of Sedimentary Rocks" by N. S. Shvetsov (1934, pp. 140 and 144), however, it was precisely these limits which were taken for sand particles and sandstones (2 to 0.02 millimeters); the lower limit in view of A. N. Zavaritskiy's critical comments, was later taken by M. S. Shvetsov as 0.1 millimeter. But the second edition of the same work (1948) mentions the existence of two concepts of sand particles, from 1 to 0.1 millimeter or from 2 to 0.5 millimeter (p. 215).

Chapter II, "The Study of Sedimentary Ore Accumulations of Iron, Manganese, Aluminum, Phosphorus and Copper," Chapter III, "The Study of Coals and Coal Shales," and Chapter IV, "The Study of Halogen Rocks" are written succinctly and interestingly and do not give grounds for criticism, except that the chapter on coal might in the future be somewhat expanded.

Chapter V "The Study of Carbonate Rocks" is not too badly written, generally speaking; the first part of the chapter, which deals with the classification and nomenclature of the rocks, nevertheless deserves a few remarks. One cannot agree with the assertion that "calcareous-dolomite rocks vary greatly in chemical composition within a single bed" (p. 285), which is given as an argument in favor of returning to the first, essentially field based, classification of calcareous dolomite rocks proposed by M. E. Noinskiy. If in certain cases, there is indeed a heterogeneity in the chemical composition of calcareous-dolomite rocks, this is most likely a

rarer rather than a commoner manifestation. In such cases thin sections should be prepared in order to establish, for example, the range in the dolomite content of the limestone, or to describe the mineral content of certain inclusions, concretions, organic remains, fragments of carbonate deposits and so on, and the cement binding them. Hence, a detailed classification of calcareous, dolomite rocks should definitely be made since the actual name of the rock often indicates the possibilities of using it in practice. The point is, which one of the classifications should be chosen?

With regard to a particular classification of carbonate rocks containing non-carbonate silt or sand, there is no need to engage in dispute in view of the conditional nature, in all cases, of the boundaries used: the subdivision suggested on page 287 of the second volume can be adopted.

The singling out of only three basic types of carbonate rocks — clastic, organogenic and chemogenic — can hardly be regarded as satisfactory at the present time; it was entirely necessary to quote the structural classification of each of these main groups (limestones and dolomites). Such subdivisions, adding more detail to the general classification, have already been in existence for a long time and are widely used.

The remaining sections of Chapter V are well written.

Chapter VI, "The Study of Silicate Rocks" was greatly cut down by the editors. But silicate rocks have not been studied sufficiently and it would be better to describe the specific nature of their investigation and genesis more fully.

Part 5, "Geochemical, Mineralogical, Paleontological and Structural-textural Criteria of a Medium in Facies-genetic Analysis of Sedimentary Rocks and Sedimentary Minerals" consists of seven chapters.

Chapter I, devoted to the weathering crust, is brief, exhaustive and interesting.

Chapter II, "Deluvial, Proluvial, Alluvial and Deltaic Deposits..." is not too bad.

Chapter III, "Basic Physico-geographical Types of Ancient Bodies of Water..." and Chapter IV, "Details of the Reconstruction of the Physico-geographical Environment in Ancient Marine Basins," written by N. M. Strakhov, are interesting and informative; the section on the gas regime in ancient marine basins (Chapter IV) is rather subjective.

Chapter V, which deals with the features of water-collecting areas as reflected in subaqueous deposits, is also interesting.

Chapter VI, "Eolian sand deposits," and Chapter VII, "Glacial deposits," are very useful for geologists, particularly geological surveyors.

The sixth part of the second volume is devoted to stratigraphic correlation by means of petrographic and mineralogical characteristics; it consists of four parts and is well written.

Chapter I, "Methods fo correlating sections by means of minerals" describes the subject convincingly, quoting characteristic examples. In Chapter II, which deals with correlation of sedimentary strata by chemical elements, using spectrum analysis, the material is given a concise and lucid exposition. Chapter II is very interesting; it concerns correlation between sections by means of concretions, and Chapter IV, which concerns the cyclical-facies method of correlating sections of sedimentary strata, is also good.

The second volume is fairly well illustrated, both in the text and in the appended tables.

Summing up the second volume of the collection "Methods of Studying Sedimentary Rocks," it should be pointed out that most of the chapters are well written; when it is republished, the above-mentioned chapters and sections which are written either badly or subjectively should be re-edited. Some of the sections in the second volume are especially bad in this respect. Since this book will have to be a methodological handbook, it should try as far as possible to avoid laying down one single conception of the views discussed as being the only true one.

It is also suggested that several chapters on the chemical analysis of rocks should be taken out and made into a separate book. Finally, the extent and number of chapters on the features of certain types of sedimentary rocks should be increased, particularly by describing the characteristic features of argillaceous rocks, sandstones and siltstones.

As a whole, the work under consideration, despite its defects, is still even at the present time of practical value to geological surveyors and beginning sedimentary petrologists.

TO THE EDITORS OF "IZVESTIYA AN SSSR, SERIYA GEOLOGICHESKAYA"

My article "Genesis of Basic Rocks in Armenia and the Adjacent areas of the Lesser

Caucasus" published in "Izvestiya AN SSSR, Seriya Geologicheskaya," No. 7, 1956, was criticized by G. A. Kazaryan, E. G. Malkhasyan and Yu. A. Leye, whose comments were published in the same journal (No. 6, 1958).

I consider it my duty to reply to the reviewer's comments.

1. The reviewers consider the list of bibliographical references incomplete, but my brief article did not intend to review all the existing views on the vein rocks of Armenia and the Soviet Union as a whole, so that the list does not include all the existing work on this subject. But the work of the greatest experts in Armenia — A. T. Aslanyan and A. A. Gabriyelan — on the stratigraphic position of intrusive complexes in Armenia, was quite naturally included among the literature sources cited by me.

As regards "Papers of the First Conference on Cosmogony," the references to this work were removed by the editors when my article was abbreviated.

2. On p. 105, the reviewers point out: "The main thesis of the article is that the basic dikes were injected after the formation of all the intrusives and their vein complexes; i. e., they are post-Upper Eocene" (page 80). This assertion on the part of the reviewers is a misunderstanding; this conclusion and the data given in four sections (pp. 80, 81 and 82 in our article) refer entirely to Central Armenian rocks, and cannot give rise to any objection. In actual fact the main point of our article is clearly formulated in the statement: "The dikes of the main rocks in Armenia and adjoining sections of the Lesser Caucasus are by no means derivatives of granitoid magma, but belong genetically to other magmatic sources." The same thing is stated on pp. 8 and 82 in describing the various age-relationships of the main dike rocks and other vein rocks, and on page 82: "The main dike rocks apparently belong genetically to different (non-intrusive) magmatic sources. Hence their injection, regardless of intrusive activity, may preceed or follow the intrusive complexes, or take place during their formation."

3. The criticism of a "single originating magma chamber (page 106) is also invalid. It is not said anywhere in the article that the basic dikes "have a single original chamber." On the contrary, in the notes on page 83 it says that these dikes are related genetically to igneous sources, and later it mentions the unity of the initial material, i. e., the material (for example of the basaltic zone) from which the magma chambers providing the basic dikes are formed. The idea that the basic dikes belong to numerous sources is also expressed in subsequent parts of the article.

4. The assertion that I included only six tendentiously selected analyses is untrue. In actual fact I used the thirteen analyses available in 1954, and not six, (the last column in the Table on page 83 gives the mean composition computed from seven analyses, but the number "7" was omitted by the editors), and the similarity and dissimilarity in the chemical compositions of the dikes from different regions was pointed out particularly.

5. Page 106 of the review says that the Jurassic age of numerous dikes of basic composition in the Alaverdi region is well known. This is G. A. Kazaryan's personal opinion, while all the authoritative investigators of the Alaverdi region consider the age of the dikes as Tertiary.

6. There can only be one answer to the reviewer's question: "Can the basic dikes in the Alaverdi or Kafan regions, which do not go beyond the Jurassic deposits (dikes of Mesozoic age), have been injected at the same time as dikes which have pushed through the Kongur-Alangez granitoid of Miocene age?" (page 106); the answer is that if the Tertiary dikes of the Alaverdi region are arbitrarily given a Mesozoic age, they can of course be contemporaries of the Kongur-Alangez dikes.

7. G. A. Kazaryan included his own ideas of the formation of vein rocks for the Alaverdi region in the review, considering these the only correct ones. In my opinion, his artificially constructed system seems to reflect the position of vein rocks in Central Kazakhstan, rather than the Alaverdi region.

It is known that so far the age of the Alaverdi intrusive rocks is controversial. V. G. Grushevoy, K. N. Paffengol'ts, B. S. Vartapetyan, A. L. Dodin and others consider them Tertiary, while the maps compiled by A. T. Asalanyan, A. A. Gabrielyan, P. Yepremyan and others show them to be Mesozoic. However, ignoring other investigatiors' data, Kazaryan confidently picks out the basic associated with both the Mesozoic and Tertiary intrusive cycles in his system. It should be pointed out as well that in his system he incorrectly uses certain petrographic terms; i. e. "Quartz-diorite porphyries," "andesite prophyrites" and others (page 106).

8. A number of facts quoted in the review have no bearing at all on the problem dealt with in our article; for example, V. N. Kotlyar's data of 1930 on the genetic relationship between all the igneous rocks of the Gyumushkhan intrusive complex (page 106) to which no one is objecting.

9. The reviewers consider the Tertiary age of the dikers of basic composition to be erroneous. Discussion of the problem is pointless, since in determining their age I have bared my conclusion mainly on the data of other investigators: N. K. Paffengol'ts, V. G. Grushevoy, B. S. Zartapetyan, A. L. Dodin and O. S. Stepanyan for the Alaverdi; V. N. Kotlar for Central Armenia; and V. G. Grushevoy, K. N. Paffengol'ts and others for Southern Armenia. The hypothesis of the existence of dikes of different ages is quite logical, but facts must be established to prove this.

10. The reviewers believe that the dikes are also genetically associated with extrusive igneous activity. This view, incidentally, was developed in the case of Armenia by A. L. Dodin, P. F. Sopko, A. T. Aslanyan, and others, but nothing about this was mentioned in the review, implying that the credit for this view is to be given to the r eviewers. We can agree with the opinion that certain dike rocks whose structure and texture resemble those of extrusives are the roots of effusive formations, but we do not think it right to see the roots of extrusive formations in vein rocks; if we are to make a clear-cut division, it would be more to the point to call them simply the roots of extrusives.

11. On page 107, the reviewers point out that the differences in the petrochemical features of the basic dike rocks and granitoids (page 107) as not entirely substantiated, but they do not produce any proof to the contrary.

12. At the bottom of page 107 it is said that: "His other allegation, that all the dikes of basic composition are post-ore, ... is unsubstantiated," and further on: "but the author's reference, as proof, to pre-ore dikes, according to S. S. Mkrtchyan and T. A. Arevshatayn, contradict his conclusions." This is untrue: page 83 of my article describes the various age relationships of the different dikes and the intrusions, the leucrocratic veins and mineralization in Armenia and the adjoining parts of the Lesser Caucasus. Furthermore, the supposition of pre-ore dikes in no way contradicts our conclusions, since we presume that their injection, "regardless of intrusive activity, may precede or follow intrusive complexes, or occur during their formation" (page 83).

13. The reviewers' statement on page 107 to the effect that the basic dikes of the Alaverdi region are only localized within the region of development of intrusives and - clearly gravitate towards them is erroneous. This may possibly be due to the fact that during their field work my opponents did not venture beyond the limits of the intrusive masses.

14. In their attempts to deny the existence of independent vein complexes in Armenia, the reviewers wrongly assert that such complexes could not have appeared in the Lesser Caucasus, since this folded zone would not have outlived the later and final stages of the development of the mobile zones (page 107). It is known, however, that little has been done so far to establish the consecutive changes in the stages of development of the lesser Caucasus folded zone. At the same time, despite the reviewers' statements, authoritative investigators of the lesser Caucasus — V. G. Grushevoy (1, page 55), I. G. Makak'yan and S. S. Mkrtchyan (3, pp. 512-514) — consider that the later and final stages in the development of the mobile zones were manifested in the lesser Caucasus.

15. With regard to the reviewer's rebuke that, in using V. S. Koptev-Dvornikov's data I made a mistake in the question of the genetic association between melanocratic veins and intrusives, I have considered it advisable to quote the actual statement in question: "although the vein rocks of the first stage are physically associated with the intrusive bodies themselves, those of the second stage probably originate from deeper magmatic sources within the crust" (2 page 75). Surely it is clear from this that, according to Koptev-Dvornikov, intrusives and the first-stage vein rocks associated with them on the one hand, and the second-stage vein rocks on the other hand, are genetically related to different magmatic sources. The reviewers have evidently been misled by Koptev-Dvornikov's assumption that the magmatic sources of the vein rocks of the second stage are granitic.

Thus we see that the reviewers have not delved sufficiently into the problem of the origin of the basic dike rocks in Armenia, and have committed a number of inaccuracies in its intrepretation.

At the end of their review, the reviewers state that they have at their disposal a "great amount of factual material" on this problem, from which they are now in the stage of drawing general conclusions. Let us wish them luck in "solving" the "real" mechanism of formation of the vein rocks in Armenia.

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BIBLIOGRAPHIC WORK ON THE SPORE-POLLEN METHOD (PALYNOLOGY)

by

M. I. Neyshtadt

Spore-pollen analysis, as is well known, is being used with great success in geology, geography and many other branches of knowledge. This method has been particularly extensively developed in the USSR.

The successful application of the study of pollen and spores to the solution of a number of questions, stratigraphic and phylogenetic, has necessitated a detailed study of the morphology of pollen and spores, which in its turn has stimulated further use of this method in other branches of science. In this connection, the term "spore-pollen analysis" has become too narrow, since it does not reflect all the aspects of this study, and has been replaced by a number of authors with other terms, of which the commonest is "palynology," meaning the entire growth of research into pollen and spores, including spore-pollen analysis.

The amount of research associated with this method is growing continually, both in the USSR and abroad. Hence, it is without doubt very important to bibliographical indices on this method, covering scientific literature from all countries, have been published practically every year since 1927 by Professor G. Erdtman of Stockholm University in the well-known Swedish geological journal, Geologiska Föreningens i Stockholm Förhandlingar. Erdtman began publishing this collection in 1954 together with the Journal which he edits, "Grana Palynologica," published by Almquist in Stockholm.

The bibliographical indices on the spore-pollen method compiled by Erdtman have acquired great fame and are used in practically all countries of the world. Nineteen indices have come out so far. Since 1957 the indices have come out under the name "Literature on Palynology."

The latest of those published — the nineteenth index — contains the following items.[1]

Bibliography.

Chemistry of pollen and spores.

Morphology of pollen and spores: a: techniques, b) general, c) dicotyledons, d) monolotyledons, e) gymnosperms, f) pteridophyta, g) bryophyta, h) other microorganisms and microfossils unrelated to pollen grains or spores.

Aerial palynology.

Melitopalynology (pollen in honey).

Analysis of pollen and spores: a) general, b) principles, c) techniques, d) pre-Mesozoic deposits, e) Mesozoic deposits, f) Tertiary deposits, g) Quarternary deposits (general work and work in different countries, the latter in alphabetical order). This includes literature on the following countries and continents: Australia, Austria, Africa, Belgium, Bulgaria, Great Britain and Northern Ireland, Hungary, Germany, Netherlands, Denmark, Iceland, Spain, Italy, Canada, China, Mexico, New Zealand, Norway, Poland, Rumania, USA, USSR (including, separately, the Latvian SSR, Lithuanian SSR and Estonian SSR), Finland, Czechoslovakia, Switzerland, Sweden, Yugoslavia, South America and Japan.

In all, 2591 works are quoted in the 19th index, including 1233 names (i. e., about 50%) on the USSR. This is work mainly carried out over the years 1953 to 1956, but in contrast to previous indices, Erdtman also gives some of the basic literature over previous years, which makes the reference work very valuable for those studying questions involving the use of spore-pollen analysis.

Collections of world literature on spore-pollen methods have also been published by Professor Helmut Gams — a great specialist on the Quarternary Period and former Secretary of INQUA. He has published nine issues of the bibliography in the journal Zeitschrift für Gletscherkunde (from 1927 to 1949).

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[1] Literature on Palynology, 19. Geol. Fören. Stockh. Förh. 79, pp. 601 to 736, 1957.

In his first index Gams makes the following basic divisions: geological and chronological bases, northern region of glaciation, extra-glacial regions, Alpine glacial region.

In subsequent issues he gives the following headings: Methods, Morphology, Chemistry, Pre-Quaternary deposits, Pleistocene, Holocene. The literature on the Pleistocene and Holocene is grouped according to country, as in Erdtman's index. It is important to point out that Gams divides the Quaternary into Pleistocene and Holocene, which Erdtman does not do.

Gams has not published any more indices since 1949, as far as we know.

Beginning in 1956, bibliographical yearbooks on palynology began to come out in Paris, published by the National Museum of Natural History. They were compiled by the French palynologists M. Van Campo and J. Roger. Up to the present time three yearbooks have come out: Palynologie. Bibliographie. Numéro 1, Décembre 1956, Paris. Muséum national d'histoire naturelle C.E.D.P. et service de palynologie. 116 pages.[2] Ibid. No. 2, January 1958, 116 pages. Ibid. No. 3, January 1959, 132 pages.

The palynological bibliographic yearbooks published in Paris are compiled on a slightly different basis from those of Erdtman and Gams. They give lists of palynologists in all countries and their addresses, which is very important.

There is no need to stress the exceptional value of this measure for the development of international scientific relations. The list in the second yearbook, for example, has 497 addresses of specialists in palynology from 40 countries: Australia, Austria, Argentina, Union of South Africa, Belgium, Bulgaria, Brazil, Great Britain, Hungary, Venezuela, Gabon, Germany, the Netherlands, Denmark, Egypt, Israel, India, Indonesia, Ireland, Spain, Italy, Canada, Kenya, China, Colombia, New Zealand, Norway, Portugal, Poland, U.S.S.R., U.S.A., Tanganyika, Turkey, Finland, France, Czechoslovakia, Chile, Switzerland, Sweden, Yugoslavia and Japan.

An analysis of this list provides interesting material. The greatest number of specialists is found in the U.S.A. — 77 people (about 16%); the second place is taken by the U.S.S.R. — 59 (about 12%) (it should be pointed out that by no means all the palynologists in the U.S.S.R. have been included); the third place is occupied by Germany — 55 persons; the fourth place by India — 47; the fifth by France — 33; the sixth by Great Britain — 32, and then come Sweden, Japan, Denmark, the Netherlands, Canada and other countries.

The second issue also contains obituaries, with information on the deaths of S.A. Yakovlev, B.N. Kozo-Polyanskiy and E. Zander (the great German expert on pollen in honey).

The material above shows that the method of spore-pollen analysis has found extremely wide application in geology, particularly coal and petroleum geology, in the study of the Quaternary system, and in geography, paleobotany, botany, agriculture, in experimental stations, in bee-keeping institutes and laboratories of medicine, pharmacology, archeology and other branches of science.

The Paris yearbooks contain the following items: addresses of palynologists, lists of their work and indices. The headings are as follows: bibliography and personal details, sporoderm composition, physical and chemical features of spores and pollen, techniques, morphology of spores and pollen (angiosperms, gymnosperms, pteridophyta, bryophyta, fungi), pollenization and fertilization, palynological analyses of atmosphere, honey, geological deposits (methods and techniques, fossil plankton, Paleozoic and particularly Carboniferous, Mesozoic, Cenozoic, Quaternary); the latter gives a breakdown into countries.

The prompt publication of new works is a merit of the edition. In particular, the number of works published since 1958 makes up 40% of the third yearbook.

The bibliography in the Paris editions is compiled on the basis of extensive international collaboration. Any author who sends in his work on palynography receives a free copy of the yearbook from the publishers.[3]

The geological information service which publishes the bibliographical indices also publishes reviews of Soviet literature and translations of certain Soviet books.

There is a bibliographical index of work on the spore-pollen method published in the U.S.S.R.[4] This bibliography contains 926

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[2] Regarding the first yearbook, see the review in "Izv. AN SSSR, Seriya Geologicheskaya," No. 6, 1957.

[3] The address of the compilers of the index: Bureaux de Recherches Géologiques, Géophysiques et minières. 74, Rue de la Fédération, Paris XV.

[4] M. I. Neyshtadt. The Spore-pollen Method in the USSR (History and Bibliography). Institute of Geography of the USSR Academy of Sciences Izd-vo AN SSSR. 1952.

works published from 1906 to 1951. Each work is annotated. The bibliography is preceded by a description of the history and development of the method in the U. S. S. R. The annotation and historical sketch make the bibliographical reference book on the U.S.S.R. different from all those described above. To make the reference book easier to use, indices are appended to it on the following: points from which the analyses are made; subject index; Republic, Kray and Oblast' indices; foreigh countries; list of authors.

CHRONICLE

SCIENTIFIC TIES WITH BELGIAN SCIENTISTS[1]

by

D.I. Shcherbakov and Ya.G. Ter-Oganesov

A year has passed since the opening of the World's Fair in Brussels — one of the most important international events of 1958.

The countries taking part in the World's Fair displayed their scientific and cultural achievements under the theme of "Man and Progress."

The Fair organizers showed great initiative and energy: about 200 national, international, specialized and private pavilions were erected in an area of 200 hectares. This required a certain amount of reconstruction of the capital, including the rebuilding of certain streets and the erection of bridges and tunnels.

By virtue of the international character of the Fair, the architecture of the buildings was greatly varied, but in most cases modern styles prevailed. Most of the pavilions, built of aluminum, concrete and plexiglass, were marked by a simplicity of design. The highest building, the 102-meter Atomium, symbolizing the advance of the atomic age, represented the iron-crystal structure and consisted of 9 spheres linked by tubular passageways, along which visitors were able to get to any part by escalator or elevator. The exhibits in the spheres were devoted to the theme "peaceful uses of atomic energy." A 35-meter slanting concrete arrow, advertising present-day civil engineering in Belgium is also noteworthy.

The pavilions which captured the attention of visitors to the exhibition, on account of their original architectural style and exhibits, were those of the U.S.S.R., Belgium, Czechoslovakia and Hungary, and also France, Britain and the Netherlands. At the same time the pavilions of the Arab countries, Thailand and the Sudan, though much smaller in size and scale of the exhibits, were of great interest and reflected the growth and development of the economy and culture of States which have only recently freed themselves from colonialism. It was therefore very surprising that the U.S. pavilion reflected neither the level of the economy and technical development of the country, nor the culture and life of the American people.

The Soviet pavilion was a very popular one at the Brussels Fair; its monumental building, made of glass and aluminum, produced an overwhelming impression. Models of the artificial earth satellites attracted great attention among the visitors.

The international palace-pavilions: the Palace of Art, where works of painting and sculpture from different countries were on show, and the Palace of Science, in which 15 countries demonstrated their attainments in the field of nuclear physics, biology, chemistry, solid state physics and other sciences, occupied a prominent place at the Fair.

Themes from geology and geography were also represented at the exhibitions.

In the Soviet pavilion visitors found stands devoted to the study of the polar regions, an artistically made model of the "North Pole" drifting station with a map of the Arctic hemisphere, which showed the polar stations, the Northern Seaway and "SP" drifting stations. There was also an exhibition of the equipment and accessories used by the polar stations, including a tent frame, movable house, hydrometeorological instruments and astronomic instruments.

Photographs showed some of the moments in the work of those taking part in the Soviet Antarctic expedition, in particular a journey by a sledge-tractor train to set up the inland "Pioneer" scientific station. The explanations

[1] Nauchnyye svyazi s bel'guyskimi uchenymi.

accompanying the photographs described the extent and results of research under the International Geophysical Year program.

The "Geology" stand showed a geological map of the U.S.S.R., on a scale of 1:2,500,000, compiled under the direction of Academician D.V. Nalivkin and showing the location of the most important minerals, and also a tectonic map of the U.S.S.R. and contiguous countries on a scale of 1:5,000,000, compiled under the direction of Academician N.S. Shatskiy. Both these maps earned the highest award, the Grand Prix. Samples of minerals, carefully chosen by the Central Geological Museum, added an effective finishing touch to the stand.

The Belgian Congo pavilion displayed a composite map of the natural resources of this very wealthy Belgian colony, a geological relief map of the Belgian Congo and Ruanda-Urunda, made of organic glass, and a number of geological maps on various scales relating to the different ore-bearing regions. Glass cases contained splendid samples of ores. A working model showing hydrometeorological conditions in the Belgian Congo attracted great attention.

The French pavilion displayed a well-made geomorphologic map of the country. The aerial surveying material and a geological map of Madagascar were interesting, but the selection of minerals was poor, with the exception of a small collection of uranium ores.

The Canadian, Mexican, Portugese, Argentinian and Iranian pavilions contained maps and samples of minerals.

It should be pointed out that cartography was well represented at the Fair, mainly by Belgium and France.

The Brussels Fair has made a contribution to international cooperation. The Soviet scientists and specialists who took part in the Soviet section of the World Fair showed great interest in the scientific attainments of foreign scientists, and evinced a strong desire to establish personal contact and relations. On the occasion of the Soviet national holidays Academician Shcherbakov gave an address in Brussels on the research carried out by Soviet scientists in the Polar regions; the address was well received, which is an indication of the great interest of Belgian scients in the work of Soviet research workers. Our group[2] established relations with a number of Belgian geologists and made visits to some of the geological establishments in that country.

Geology is most high developed at Liège University, where most of the Belgian geologists have been educated. But the laboratories and work rooms at the University (particularly the mineralogical laboratory) suffered greatly through the German occupation during World War II, and have not yet been properly restored.

We established personal contact with the following scientists of Liège University:

P. Fourmarier, Professor Meritorius, member of the Royal Academy, Chairman of the Geological Committee of the Ministry of the Colonies. He is known for his research in the Belgian Congo. Professor Fourmarier greatly praised the work of Soviet geologists, noting the great contribution to world science made by geologists of the U.S.S.R. over the last 20 years.

C. Ancion, President of the Belgian Geological Society, Professor at Liège University and Chief Geologist of the Charleroi Coal Company, known as a great specialist in the sphere of applied geology.

L. Calembert, Professor at Liège University, Deputy President of the Belgian Geological Society, a great specialist in petrography, metallogeny and applied geology. His assistant in petrography is A. Michot, who was recently graduaged from Liège University and gave a report at the meeting of the Geological Society on the petrography of the anorthosite massif in Norway, which we attended.

Mme. S. Leclercq, Professor at Liège University, micropaleontologist, is in charge of the paleontological laboratory at Liège University; she has developed a new method of microphotographing sections for studying microfauna. She expressed a desire to have a Soviet micropaleontologist working in her laboratory and would like herself to work in the micropaleontology laboratory of the Geological Institute of the U.S.S.R. Academy of Sciences.

F. Schellinck, Professor at Brussels University, head of the Laboratory of Petrography, Mineralogy and Geochemistry. He is a member of the Board of the Soviet-Belgian Friendship Society and has always had a sincerely friendly attitude toward the Soviet Union.

Our group went to see the Musée du Congo Belge, located in the suburbs of Brussels. The museum exhibits the natural wealth and fauna of this Belgian colony.

The geological section of the museum

[2] Professor N.P. Yermakov and geologist T.T. Matrenitskiy joined with us in establishing ties with the Belgian scientists.

contain samples of ores and rocks from the Belgian Congo, as well as geological maps of different parts of the Congo and Ruanda-Urandi. It also contains facts and figures concerning the history of the geological study of the Belgian Congo during its assimilation, as well as research in the past years.

The extensive prospecting and research work in the Congo has led to the discovery of large deposits of copper, cobalt, uranium, diamond and lead, and lesser amounts of gold and other minerals. The Congo takes first place in the capitalist world in diamond and cobalt mining, fourth place in copper and tin mining, and seventh or eighth place in zinc mining.

The mineral resources of the Congo are concentrated in several regions. The Katanga region in the south-east contains a copper-bearing zone, with deposits of copper and the associated minerals, cobalt, silver, zinc, cadmium and germanium. The Kazolo-Shinkolobwe uranium deposit is in this region. Also to be found here are manganese and iron ores, coal and lead. The northern part of this region is known for its tin deposits. About 70% of the entire exports of the Congo coal mining industry comes from the Katanga Province.

The southwest region is noted for rich diamond deposits. There are two sub-regions here: 1) Chikapa, where deposits of gem diamonds are found, and 2) Bakwanga, noted for its industrial diamond mines.

The northern and middle-eastern regions are marked chiefly by tin and gold resources. The Kivu-Maniema subregion is noted particularly for lead. Gold-bearing zones are located between 5° south latitude and the northern border of the Congo, of which the most important is the Kilo-Moto subregion, which provides about four-fifths of the entire gold output.

Of particular interest is the copper-bearing zone stretching from northwest to southeast through the territory of Upper Katanga for more than 300 kilometers, with a width of 50 to 60 kilometers. In the south it continues into the territories of Northern Rhodesia. The copper-bearing belt includes three groups of important deposits. These deposits are classed as cupriferous sandstones. The thickness of some of the strata varies from 2 to 35 meters. The ore is noted for its high copper content. The origin of these deposits has not yet been finally established. An important component in the ores of the copper zone is cobalt. The average cobalt content in the ores is 0.05%, but in certain cobalt-rich sections it is as much as 0.3-0.5%. At the Kolwezi Plant, germanium is extracted from the dust which settles in the chimneys of smelting furnaces.

The Congo and its widely varied deposits are being studied avidly by Belgian geologists. A school of regional and mining geology has grown up and developed in the Congo. It has published extensive scientific literature.

The geological section of the museum employs a group of geologists supervised by I. Lepersonne and L. Cahen, great experts in the geology and deposits of the Belgian Congo, with whom we established personal contact. Since World War II, this group has published a number of geological monographs, as well as geological and tectonic maps of the Belgian Congo and Ruanda-Urundi on the scale 1:2,000,000, and a bibliography of geological work carried out in the Belgian Congo from 1819 to 1956, with annotation of most of the mentioned publications.

Particular mention should be made of L. Cahen's book, "Geology of the Belgian Congo," which has recently been translated into Russian and published in our country, (Foreign Literature Press, Moscow, 1958). This book is a collection of papers on the geology of the Belgian Congo published separately in a number of periodicals, and contains a survey of the mineral resources, and also the latest data on the absolute age of the ancient Belgian Congo rocks. It will undoubtedly be of great interest to a wide circle of geologists.

Now a few words on the Belgian Geological Service.

Belgium is a small country, but very interesting in its geological structure and mineral wealth, which chiefly supplies the coal industry.

The area of Belgium is not very large, only 305,000 square kilometers. By the end of the XIX century a geological map of the country, on a scale 1:300,000 had been completed. Over the last fifty years there have been geological surveys on large scales (1:10,000 and 1:25,000) of different parts of Belgium, mainly the coal regions by a group of geologists (6 in all) under the supervision of the engineering geologist Grosjean, director of the Belgian Geological Service. His duties include supervision of the proper exploitation of mineral resources developed within the country (not including colonial possessions).

On the occasion of the International Geophysical Year, Belgium organized an expedition to the Antarctic, the leader of which was F. Basten, who visited the Soviet pavilion and ma made a detailed study of Soviet hydrometeorological instruments and Arctic equipment.

The personal contacts and relationships

which we established this year with the group of Belgian scientists is only the first step towards scientific cooperation. They must be developed and strengthened.

The Brussels Fair has made a contribution to peaceful cooperation and competition between large and small countries, whereby it justified its main aim, which was to assist human progress.